Final Technical Report

Project Title: Collection, Commercial Processing, and Utilization of Corn Stover
Award Number: DE-FC36-03ID14216 (formerly DE-FC07-03ID14216)

Project Objective: Project objective is to (1) develop and test new technologies that harvest, transport, store, and separate corn stover to consistently supply clean, raw materials to downstream processors in the bioproducts industry, and (2) to engineer a fermentation system to meet performance targets for lactic acid and ethanol manufacturers.

Recipient: NatureWorks LLC (formerly Cargill Dow LLC)
Project Location: Minnetonka, MN

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Cost-Sharing Partners: Mat Inc., IronHorse Farms, Iowa State University, John Deere, Midwest Laboratories

Subcontractors: Mat Inc., IronHorse Farms, Iowa State University, Wallace Foundation, John Deere, Midwest Laboratories

Project Period: March 1, 2003 to May 28, 2007

Executive Summary:
The two main objectives of this project were:
1) to develop and test technologies to harvest, transport, store, and separate corn stover to supply a clean raw material to the bioproducts industry, and
2) engineer fermentation systems to meet performance targets for lactic acid and ethanol manufacturers.

Significant progress was made in testing methods to harvest corn stover in a “single pass” harvest mode (collect corn grain and stover at the same time). This is technically feasible on small scale, but additional equipment refinements will be needed to facilitate cost effective harvest on a larger scale. Transportation models were developed, which indicate that at a corn stover yield of 2.8 tons/acre and purchase price of $35/ton stover, it would be unprofitable to transport stover more than about 25 miles; thus suggesting the development of many regional collection centers. Therefore, collection centers should be located within about 30 miles of the farm, to keep transportation costs to an acceptable level. These collection centers could then potentially do some preprocessing (to fractionate or increase bulk density) and/or ship the biomass by rail or barge to the final customers. Wet storage of stover via ensilage was tested, but no clear economic advantages were evident. Wet storage eliminates fire risk, but increases the complexity of component separation and may result in a small loss of carbohydrate content (fermentation potential). A study of possible supplier-producer relationships, concluded that a “quasi-vertical” integration model would be best suited for new bioproducts industries based on stover. In this model, the relationship would involve a multiyear supply contract (processor with purchase guarantees, producer group with supply guarantees). Price will likely be fixed or calculated based on some formula (possibly a cost plus). Initial quality requirements will be specified (but subject to

refinement).Producers would invest in harvest/storage/transportation equipment and the processor would build and operate the plant.

Pilot fermentation studies demonstrated dramatic improvements in yields and rates with optimization of batch fermentor parameters. Demonstrated yields and rates are approaching those necessary for profitable commercial operation for production of ethanol or lactic acid. The ability of the biocatalyst to adapt to biomass hydrolysate (both biomass sugars and toxins in the hydrolysate) was demonstrated and points towards ultimate successful commercialization of the technology. However, some of this work will need to be repeated and possibly extended to adapt the final selected biocatalyst for the specific commercial hydrolysate composition.

The path from corn stover in the farm field to final products, involves a number of steps. Each of these steps has options, problems, and uncertainties; thus creating a very complex multidimensional obstacle to successful commercial development. Through the tasks of this project, the technical and commercial uncertainties of many of these steps have been addressed; thus providing for a clearer understanding of paths forward and commercial viability of a corn stover-based biorefinery.

Detailed Project Summary

Task 1.1 ***Harvesting Technology (ISU)***

Introduction / Statement of Project Objectives

The overall goal of this project is to initiate, design and build new and effective corn stover harvest and transport systems. Specifically:

- Harvest stover at any level of moisture while the corn grain is being harvested.
- Optimize density of the stover to ensure better loading of transporters.
- Evaluate transport options to maximize load efficiency
- Prepare appropriate information and reports related to project activities that will ultimately generate design information leading to the commercialization of biomass harvest, separation, handling and transport equipment.

Harvest methods and systems were pursued, and the necessary equipment developed to collect stover. To reduce the harvest costs, such as labor, fuel, and equipment, single pass equipment was the primary focus of this project. The following equipment was utilized in development and testing to rapidly harvest or improve the harvest of stover:

- Combine with processing and collection equipment
- Pull type machine for field testing gathering heads
- Corn head with chopping equipment
- John Deere row crop head with snapping rolls
- Corn head with horizontal snapping rolls
- Stover Cart
- Compaction Trailer

Corn harvest is predominately limited to the month of October and the opportunity to conduct field test then can be further limited by weather. Several measures were taken to maximize the window for testing. For each crop season, both short and long season corn varieties were planted. This extends testing, provides multiple crop conditions, and provides the opportunity to test over several months. For winter and spring testing whole corn plants were harvested in the fall and stored. To aid in research the following equipment was acquired specifically for this project:

- New Holland roto-slicer
- Claas corn head with chopping attachment
- Kuhn Knight manure spreader
- Gehl manure spreader
- 1000lb compression and tension scale system
- Koster Forage Moisture Tester
- Nasco Forage Particle Separator

Harvesting Equipment Development

A. New Holland Roto Slicer Mounted on the Deere 9750 STS Combine Fitted with JD 853A Whole Plant Head:

(Tested between March 2003 and June 2004)

Objective: To replacing the conventional flail chopper found on combines with a slicer unit in order to (a) cut the stover to controlled lengths, (b) reduce power demand of chopping.

Fitting a slicer in place of the conventional chopper on a combine is an innovation for which there is no recorded precedent. Straw slicers were first popularized in Europe on balers and self-loading wagons (laderwagen) and are gaining in popularity in North American balers but their use on combines has never been reported. The slicer concept was selected because it has the potential to cut stover to more precise lengths and at a greatly reduced power demand compared to traditional combine choppers, which in any case are not designed for whole plant corn material coming through the combine. Slicing units have the potential to cut stalks with as little as 1/4th the power of a forage cutter head. A slicer unit was acquired courtesy New Holland Pennsylvania to test the hypothesis that a slicer could indeed be used on a combine. The New Holland roto-slicer is a low horsepower pre-cutter used on a large round baler. In normal operation it requires approximately 20 horsepower and operates at about 150 RPM. With the most aggressive setting the precutter gives an average cut length of about 4 inches ranging from 3 to 6 inches. These smaller pieces of stover will be beneficial for handling and transportation. From the roto-slicer, the chopped stover passes onto a 30 inch wide conveyor. This conveyor is mounted on a Farmhand side dump ear corn wagon pulled behind the combine.

The plan was to

- Assess cut length of stover leaving the processor of a combine that is harvesting whole plant materials.
- Determine crop orientation as it enters into the slicer unit, since orientation was determined from a set of preliminary lab tests to be critical to actual cut length.

The performance of the slicer on STS combine with a whole crop head was tested in the short season corn. The head used on the STS was a soybean row crop head, not specifically designed for harvesting corn and stalks. This resulted in uneven or bunch feeding into the threshing area. It became evident during operation that the head was the limiting factor, not the machine capacity.

Cut length is dependent on the direction the material enters the slice where orientation parallel to the slicer axle results in the shortest cut length. Stalks leaving the combine rotor are generally randomly oriented. Airflow in the cleaning shoe tends to reorient stalks perpendicular to the axis of rotation, minimizing their air resistance, and that results in an increased length of cut on many particles. To minimize cut length the material should enter a slicer parallel to the rotor axis. Initial testing showed that grain was harvested effectively and the size of the biomass particles was reduced compared with chopping, with the majority less than 3 inches long. However, the harvest operation with the prototype setup slowed grain harvest considerably; a point that has to be seriously considered.

Slicer capacity seemed adequate but the stover-cutting performance left much to be desired. Crop orientation as it enters the slicer is the most significant factor in determining cut length. Visual inspection and video footages were used to determine that the crop flow requires orientation to maximize cutting effectiveness through a slicer. The cut length of the non-oriented crop flow was shown to vary beyond acceptable levels. Tow test stands were constructed to evaluate two methods to suitably-orient the crop flow into a slicer. Slicer power testing indicated that the slicer uses considerably less power than a conventional straw chopper on a combine. This is important because a whole plant harvester is dealing with much more straw than in a regular grain-only harvest.

We have tried two strategies, (1) to mechanically reorient the crop as it enters the slicer with a mechanical combing or raking action. However, it has been determined that with the relatively narrow body width of the combine cleaning system and the high stover feed rate, the crop mat is too thick to be effectively reoriented mechanically;

(2) to reduce cut length by deploying additional cutting surfaces between the original knives. Additionally, the space between the knives was partially blocked to prevent stalks from passing through the system endwise and uncut. As expected the modifications increased power requirements and the feed rate decreased substantially. However, the resulting cut length was improved. We have learned that Claas of Germany have a slicer that is said to cut at ¾ inch (compared with 2 1/2 inch on the New Holland slicer).

The distribution can further be improved by selecting the optimum location of the stalk entry relative to the position of the slicer. Laboratory tests indicated that feeding material such that it fell near the top of the rotor, compared to near the stationary knives improved the cut length distribution.

Reducing the cut length and the distribution of particle size with the slicer position and feed method is more beneficial than adding cutting knives. More cutting surfaces would cause a larger increase in power consumption and decrease the feed rate.

Field testing with a whole crop head, such as the JD 853, increases harvested stover yield, the initial indications were that there is a 50% stover yield increase associated with using a whole plant head compared with a conventional corn head, due to improved stalk collection. It could be argued, however, that certain commercial modifications for the conventional corn head could be used to increase the quantity of leaf material collected.

On October 31, 2003, this equipment was demonstrated as part of a field day for project members; see Figure 1.1 below. Additional work on this device was terminated due to change of Principal investigator at Iowa State University, and the identification of more promising technology solutions.

Figure 1.1 Combine, Roto Slicer, Whole plant head

B. The Two-Tier Prototype Head

(Work done between March 2003 and March 2004).

The Two-Tier head – a whole plant harvesting machine - was designed to harvest and separate the ears without shelling then integrate the ears (which have a density of 45 lb/ft^3) with the chopped stover in order to have a high density load in the transporters. The aim is 20 lb/ft^3 for the mixture, 67% higher than baled corn stover.

A "Two-Tier" test stand was constructed to further test the principle of horizontal snapping rolls. Different methods to feed the entire corn plant into these snapping rolls were explored. Multiple arrangements of deck plates and snapping roll angles were tested to provide optimum feeding while minimizing the shelling and grain damage.

The Two-Tier head design incorporated:

- Dual conveyors for positive crop feed
- Snapping plates intended to eliminate butt shelling.

Based on early results from the test stand, the feed mechanism on the 6 row head was modified to provide positive control of the crop as it is fed into the snapping rolls. This allows the crop to be fed between snapping plates to eliminate butt shelling problems previously experienced. The modifications had limited success due to different geometries between the test stand and the actual head. There are some physical constraints with feeding stalks *thin end first* into a pair of snapping rolls that were configured to deal with stalks butt end first. This issue remains to be investigated further.

The unit here was a machine with a giant pickup reel. Modifications involved improvements for positive feed belts on part of the head. Initial indications showed improved feeding of the whole plant stalks into the horizontal snapping rolls. A lab test stand was used to test orientation and hold-down belt configurations and simplify adjustable geometry. Testing these modifications was done in the field.

Based on the field tests, the twin compression feed belt system was modified and changes were made to improve the position of the snapping rolls relative to the feed belts. These adjustments did improve the feed of cornstalks into the system. However, problems still exist with plants that are not fed into the machine orientated with the direction of belt travel. The modified system, incorporating deck plates, nearly eliminated the initial design problem of butt shelling. On October 31, 2003, this equipment was demonstrated as part of a field day for project members, See Figure 1.2 below.

Figure 1.2 Two Tier head.

C: *Claas Corn Head:*

(Work was conducted between March 2003 and December 2004)

Objective: Prepare a basic design that (a) reduces the overall theoretical length of cut and (b) allows the gathering head to be quickly mounted on a tractor as a whole crop harvester that collects the corn plants, processes the stover, and loads the material into a transporter. This eliminates the need for a combine and makes more use of a tractor.

Claas in Omaha graciously donated a folding (4 row) head for this work. New Holland loaned a TV 145 Bi-directional tractor for this activity.

A single row unit from a Claas prototype head with chopper attachment has been tested. The unit has a standard corn head snapping roll and deck plate arrangement. The unique feature of this machine is the horizontally spinning blade, similar to a lawn mower. Plant material is cut off by the blade and then passes through the snapping rolls to be collected. Initially the head works like a normal commercial corn head, but underneath a conveyance was designed to capture the biomass chopped by the underslung chopping mechanisms. A cross-auger conveys the stover to the left side of the head.

The modified Claas head has a theoretical calculated cut length of about 2.5 inches. However, in previous laboratory testing significantly larger cut lengths were observed. For this reason a Vermeer slicer, similar to the New Holland unit that was used for laboratory work, was included in the design. The modified Claas head, equipped with the Vermeer rotary slicer, provided a noticeable improvement of cut length uniformity. Previous laboratory testing, on the similar New Holland rotary slicer, indicated the opportunity for reduced length of cut by adjusting the feed location and stalk orientation. However, due to space constraints, these modifications were not incorporated in the design. These modifications provide potential for further performance improvement with future designs and refinements of the current harvest machine.

Transferring the stover and ear corn from the harvester to the transport vehicle posed some challenges. Conventional forage harvest machines have incorporated blowers to convey the material. However, blowers damage ear corn and typically have a low efficiency of near 25 percent. Rubber belt conveyors lose significant capacity at increased angles of inclination. At low inclinations, the conveyor become too long and heavy to achieve the desired loading heights associated with the low density stover. A paddle type conveyor was tested as a means to convey chopped stover and a mix of chopped stover and ear corn. This type of conveyor can easily move the chopped stover, but care must be taken in the design to eliminate pinch-points that damage ear corn. The test stand showed positive results even at a near vertical orientation.

Construction work on the modified Claas head was completed in Fall 2004 and the unit sent to the field for test purposes. The corn crop used in testing had an average harvested yield of nearly 200 bushels per acre and a grain moisture content of about 22%. Paired tests were utilized to eliminate field variability when comparing single stream harvest, stover only, with a combined stream harvest of stover and ear corn.

The combined stream harvest provided a bulk load density of about 7.9 pounds per cubic foot (lbs/ft^3) compared to single stream bulk load density of around 2.9 lbs/ ft^3. The optimum bulk density for road transport, to reach maximum legal load on a semi truck and trailer, is slightly over 11 lbs/ ft^3. The moisture content of the stover was about 35% on a wet basis. Cut length, one of the factors that largely influences bulk transport density, was improved significantly with the addition of the Vermeer rotary slicer. The ideal cut length from this rotary slicer would be equal to the knife spacing of approximately 2.75 inches. After the Vermeer slicer greater than 70% of the sample, by weight, had a length of cut less than 4 inches inches.

The prototype design had several design problems, largely due to the base equipment, that should be corrected. The Claas corn head was overly aggressive when operating in dry conditions and caused unacceptable butt shelling. The ground clearance of the complete machine was an extreme limitation. Both the rotary slicer and the unloading paddle conveyor were mounted too close to the ground. The stover discharged from the rotary slicer had a tendency to bunch up in the slicer and feed into the conveyor unevenly. The paddle on the conveyor were manufactured with too tight of tolerances and had some interference issues during operation. The other limitation was the overall weight and distance the head was placed ahead of the front axle. This caused the front axle to be overloaded. Even with these problems, the overall concept of the machine worked and with some refinements, it could be used to supply the bio-refinery concept with both corn grain and corn stover biomass. Photographs of the unit are included as Figures 1.3 and 1.4.

Figure 1.3 Claas Head mounted on tractor

Figure 1.4 Claas Head, in action

Conclusions
Preliminary harvest tests indicate fairly successful stover collection and processing with a New Holland Roto Slicer fitted to the John Deere 9750 STS Combine with JD 8653A whole plant head. Grain is harvested effectively and the size of the biomass particles is reduced, with the majority less than 3 inches long.

The Two- Tier prototype head requires further research and modification. While the crop conveying principles were successfully demonstrated, the complexity of the current multiple belt conveying system makes the machine complex and vulnerable. Simplification of the belt system and geometric improvements should greatly improve the machine's performance and reliability.

Field testing of the Claas head biomass harvest machine provided some valuable insights into the potential advantages and problems associated with the single stream harvest concept. Continued analysis of the data collected is expected to provide some missing pieces of the biomass puzzle. The resulting bulk density from the test machine was not as high as desired. One alteration that should be tested is a squeeze belt type conveyor. This would likely reduce shelling and grain damage. This type of conveyor would also give some pre-compaction and take advantage of the creep phenomena exhibited by corn stover. The load depth during the test was about 4 feet, increasing this to 10 feet would also increase the bulk load density significantly. Pairing the modified Claas head and rotary slicer reduced the effective cut length and helped achieve a higher density. Feeding the material into the slicer with an auger, running parallel to the slicer rotor, is believed to result in the superior stalk orientation. Further testing should be conducted to verify results for different stover moisture contents and feed rates that were not tested due to time, weather, and funding constraints.

<u>Densification Research:</u>
A critical area of biomass harvest is transporting the high volume of feedstock from the field to the storage area. Achieving a high density makes this a more economical load. One method that greatly increases the density and also aids in preprocessing is to chop the stover into smaller pieces. For example a sample of stover in 12 inch pieces, with ear corn added in, has a density of approximately 4.0 lbs/ft^3. The same sample, chopped into pieces less than 0.75 inches and with the whole ear corn added back in, reached a density over 13.5 lbs/ft^3. Several different methods to reduce particle size in the field with the minimal power input have been explored.

Particle Reduction Options:
- Claas hydraulically driven forage harvester
- Redekop Chopper
- TSR Straw Chopper
- New Holland roto-slicer from round baler
- Claas roto-slicer from square baler
- Bear Cat flail type wood chipper
- Morbark Industrial Tree Chipper

D. Harvested Stover Density Research:
(Work conducted Oct 03 – Dec 05)
A persistent problem with stover collection is the low bulk density and resulting high transportation costs associated with delivering the product to the industrial processor. Very little research has been conducted to demonstrate what levels of density are achievable. The objective was to contribute to a data base on stover density.

Information on the bulk density of corn stover biomass is limited. Increasing stover bulk density while maintaining low specific power for compression is critical in reducing the transport cost for biomass harvest. A relationship between compressive force and bulk density exists for different hay type crops. The goal of this work is to determine the relationship between compressive force and bulk density for corn stover biomass to aid future work on developing cost effective biomass harvesting systems.

Sintech MTS test machine
Several preliminary tests to find the relationships between force, volume and density were conducted using the Sintech MTS test machine. Research has been conducted using dry stover samples at 10% MC comparing applied force and the resulting density. It was found that a corn stover sample with whole ear corn, initially at 5.4 lbs/ft^3 reached over 10.5 lbs/ft^3. The MTS is also currently being utilized to find a relationship between the depth of the stover and the force required to compress it. With this data the goal is to find the optimum frequency for compaction.

The effect of length of cut, presence of ear corn and moisture content on the relationship between applied pressure and bulk density were analyzed in this study. Tests were conducted with two moisture contents and five lengths of cut (13, 25, 50, 100, 150 mm) and the presence or absence of ear corn. The objective is to develop a baseline mathematical relationship between bulk density and important factors such as length of cut and the presence of whole ear corn. It was found that the modified Kaminski model could be utilized for stover compression data. The modified equation was as follows:

$$B = D_0 + k * (P)^n \quad \text{...} \quad (1)$$

Where, B represents the bulk density of corn stover compacted by the applied pressure load P. The term D_0 represents the initial bulk density without an applied load. The parameter k influences the initial slope of the density curve and is related to length of cut and presence of ears. The parameter, n relates to the curvature of the pressure density line. This was affected by cut length and moisture content. Figure 1.5 shows a plot of dry bulk density for different cut lengths and inclusion of ear corn in the sample.

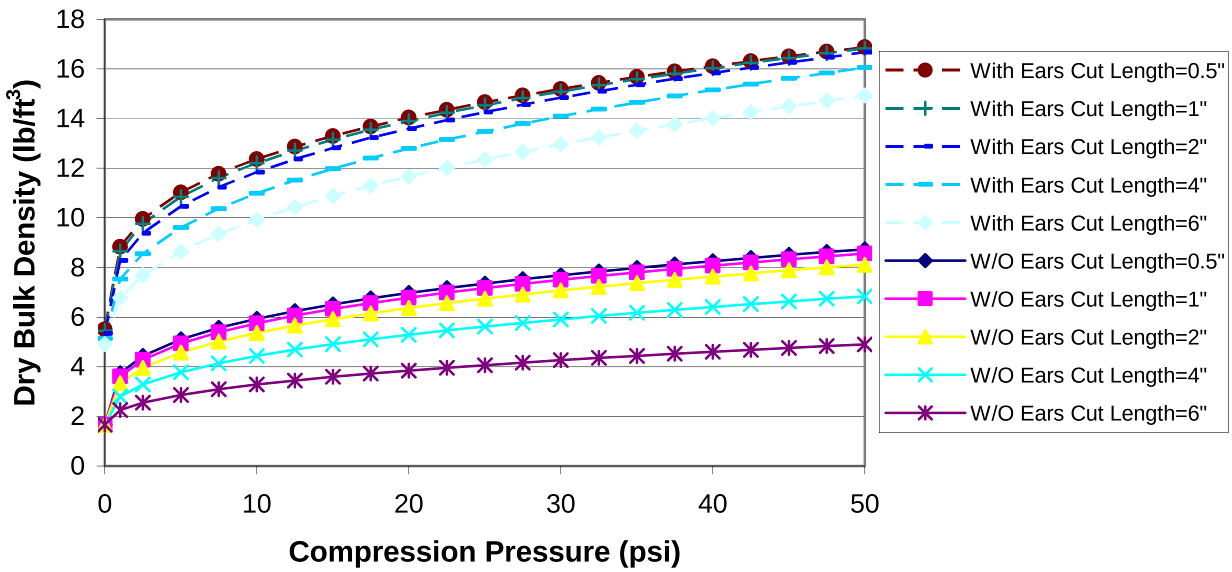

Figure. 1.5 Plot of dry bulk density versus applied compression pressure for low moisture content treatments, based on the modified Kaminski model.

The inclusion of ear corn in the sample approximately doubles the initial bulk density, but does not significantly change slope and curvature of the compression process. The figure shows that the initial compression forces do the majority of the densification, with approximately 70% of the total average densification is completed with the initial 10-psi compression forces. Therefore, large compressive forces are not warranted due to the small incremental increase in density. The predicted bulk density values, shown in Figure 1, demonstrates that as cut length decreases below 51 mm (2 inches), for any given treatments of moisture content and ear corn presence, the bulk density lines appear to converge. This shows that there is a limited change in density between the different cut lengths for a given applied pressure and indicates that processing the stover to lengths shorter than about 51 mm (2 inch) does not significantly benefit the densification process.

E. Harvested Stover Density and Transport Research:
Objective: Development of a more detailed knowledge base regarding stover harvest and transportation efficiency.

A model has been developed to explore the costs of biomass harvesting with regard to different harvest methods and shipping systems. The biomass harvesting systems are compared to the standard grain harvest system to evaluate their potential to increase the producer's net profit. The net profit is based on corn stover yield of 2.8 tons/acre and purchase price of $35/ton. The model compared two basic harvest systems. The first prototype system in the model, based on a class 7 combine, utilizes a whole crop harvesting head, a low power rotary stover processing unit, and a blower to provide transfer of the stover to a transport vehicle. This single pass, dual stream system produces a separated grain stream and a stover stream for transportation. The second harvest system is based on a standard four-row corn header equipped with a rotary chopper. The ear corn is stripped from the stalk, in the same way that a regular corn header functions, while a rotary cutter/slicer cuts the stover plant into segments. These two streams are then combined for transportation. This single pass, single stream system produces a single stream of processed stover mixed with whole ear corn, instead of two independent streams of corn grain and corn stover, and requires separation of corn at a central location.

The machines that are compared to the standard combine harvest system are variations of the prototype machines developed at Iowa State University. Continuous transfer systems (CT) indicate that the harvester has no storage capacity for the stover component and that a transport vehicle must be along side at all times to catch the material. Stover Storage systems (SS) denote a machine that has the capability to store stover and convey the material to a transport vehicle on the go. Two different shipping methods were included in the model. The first system utilized 'tractors' and high capacity self unloading wagons and the second system utilized 'semi' trucks with high capacity self unloading trailers

The model was set up such that the stover was field harvested and transported over a longer distance, possibly directly to the processing facility. The harvest systems that included stover collection were all more profitable than harvesting only grain for shipping distances less than 11 km (7 mi). The two most profitable systems, in the short distance scenario of 11 km (7 mi), are the combine equipped with stover storage utilizing semi trucks to transport and the tractor mounted harvester equipped with stover storage utilizing semi trucks for stover transport. The net profit for these systems is $101 per ha ($41 per acre) with a shipping cost of $116 per ha ($47 per acre) and nearly $90 per ha ($40 per acre) respectively.

The tractor and wagon transport systems resulted in lower profits and had shipping costs ranging from $138 to$165 per ha ($56 to $67 per acre) compared to $101 to$133 per ha ($41 to $54 per acre) for semi truck transport. As shipping distances approached 40 km (25 mi), all stover harvesters were less profitable than harvesting grain alone. When the stover and grain shipping distances reach 48 km (30 mi), all stover harvest systems result in a net loss, but the grain harvest system still allows a $15 per ha ($6 per acre) net profit.

When shipping distances up to the 11 km (7 mi), all the grain and stover harvest systems are more profitable than harvesting just the corn grain. Long distance shipping adds a variety of challenges to stover harvest systems such as labor needs and increased equipment requirements. Depending on the stover harvest system, more than 10 transport vehicles and operators may be required to service a single harvester with a 48 km (30 mi) ship distance. The harvest systems that utilized semi-truck were much more competitive than the tractor-only based transportation systems. This was due to the higher capital costs and labor requirements for the pure tractor based shipping equipment,

Shipping costs are one of the primary factors that will affect the net profit of stover harvest systems, as shown in Figure. 1.6. In conventional grain harvest systems, shipping makes up about 36% of the total harvest cost. The cost of transportation for 11 km (7 mi) ranges from 50% to more than 60% of the total stover harvest cost. When the shipping distance is increased to 48 km (30 mi), the cost of shipping grain reaches 53%, and the stover shipping costs range from 57% to 81% of the total harvest costs. This emphasizes the need to improve stover transport technology and minimize the potential shipping distance.

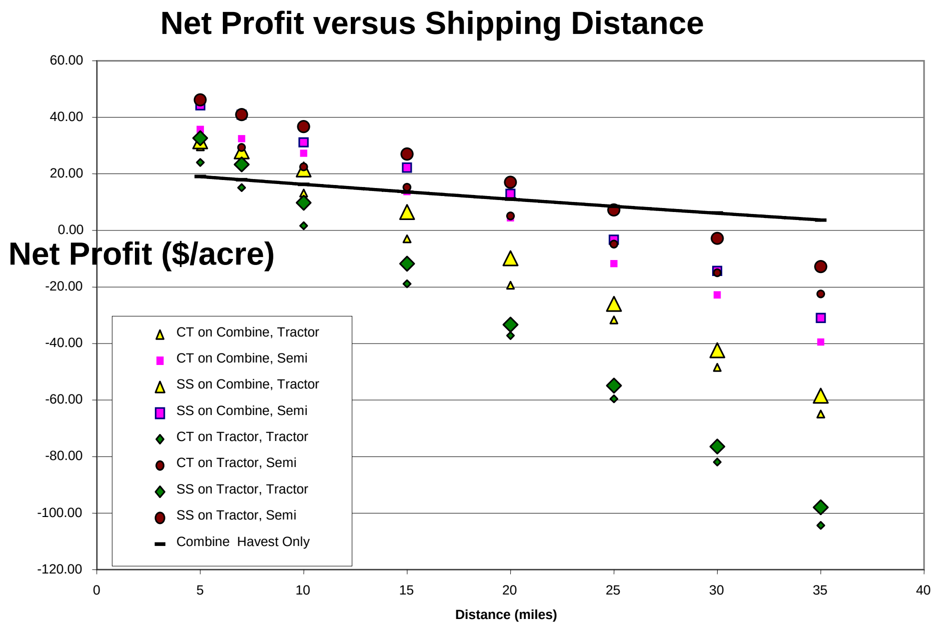

Figure 1.6. Estimated Net Profit for different single pass harvesting systems, based on 3 ton/acre stover yield and $35/ton purchase price.

Conclusions

The economic model indicated that well over 50% of the total harvest cost was associated with the transportation of corn stover to the processing facility. This made it a critical factor to be considered in the development of new harvest technology.

As shipping distance increased, this became an even more significant challenge and the feasibility of tractor based transport systems rapidly diminished due to lower travel speed and higher initial investment. Increasing the bulk density will make the semi truck based shipping systems more feasible by increasing the amount of stover transported per load.

The addition of ear corn to stover almost doubles the initial bulk density but does not significantly affect the subsequent compression process. The initial compressive forces result in the highest percentage of densification due to the reorientation of stalks to fill void spaces, and higher compression pressures are not justified. Decreasing the cut length beyond the 2 inch cut length resulted in very small increase in bulk density for any given pressure. This limited change suggests that processing the stover to further decreasing the particle size does not result in a large enough increase in bulk density to justify the processing cost. In general, it will be difficult to achieve the necessary bulk density to achieve the weight limit for truck transportation.

<u>Collaboration and Outreach</u>

F. Collaboration with Industry:

Objective: Develop working relationships with industry involved in the harvest and utilization of corn stover as a feedstock to promote the future of the biomass industry.

A field demonstration and biomass forum, jointly hosted October 22 2004 in Harlan Iowa, was aimed at distributing information about biomass harvesting and storage technologies to potential stake holders in the developing biomass industry. Approximately 50 representatives from companies and universities, primarily from the Midwest, were present to learn about new biomass technology. The two most common uses for the corn stover, planned by the attendees, were as a combustible fuel energy source and for chemical synthesis. A variety of different ideas and information was shared through discussion and presentations.

Presentations were given by Robert Kean, Cargill-Dow LLC, on the developments and uses for corn stover biomass at Cargill Dow LLC. Tom Schechinger, IronHorse Farms Inc, presented on the storage and processing technology research conducted at the Mat Inc. facility. . Bill Ridgley, Agriland FS Inc, talked about his company’s biomass harvesting and transport system. Daniel Frohberg, Iowa State University, discussed harvest equipment development and the density research work completed at the university. After the presentations attendees were given a tour of the Mat-Ag-Fiber production facility and the opportunity to see two corn stover biomass harvesters in operation.

Adverse weather conditions limited the field demonstration to a short pass for each machine. The first harvester, co-developed by Agriland FS and Iowa State University, was a bi-stream machine that separated the grain from the stover (see figure 2.1 below). The harvester was comprised of a stover processing attachment mounted on a combine. Stover was then collected in a biomass transporter developed by Agriland FS. The second machine was a single stream harvester developed at Iowa State University (Figures 1.3 & 1.4 above). The machine collects the whole plant and separates the stover from the ear corn. The stover is then processed into smaller particles and recombined with the ear corn. The mixture is then loaded on a transport vehicle.

G. Stover Harvest Collaborative Research:

Objective: Development of a more detailed knowledge base regarding sustainability and economic implications of stover harvest.

During the fall 2005 harvest season, biomass harvesting continued utilizing a prototype single pass harvesting systems. In addition, a collaborative field research was established with the Idaho National Laboratory Bioenergy Initiative (DOE-INL), and USDA Agricultural Research Service (USDA-ARS) to assess the impact of corn stover removal on the subsequent years’ corn production and soil sustainability, and evaluate the economic value of the potential ethanol from various harvest and removal scenarios.

A prototype single pass harvest system in the model, based on a class 7 combine, utilizing a whole crop harvesting head, a conventional chopper, and a blower to provide transfer of the stover to a transport vehicle, was used in the corn stover harvest. This single pass, dual stream system produces a separated grain stream and a stover stream for transportation. The harvest system was utilized to evaluate four different stover harvest materials. In the first case, the combine head was set to harvest as low as possible removing 100% of the stover material from the field (100% Removal). In the second case, the combine head was adjusted to harvest all the material from below the corn ears to the top of the plant (Top 50% Removal). In the next case, a second pass was used to harvest the remaining stover below the corn ears (Bottom 50% Removal).

This system was utilized in the establishment of a 3 year, collaborative field scale experiment with the USDA-ARS and INL lab. The treatments were 100% removal, Top 50% removal, Bottom 50% removal and 0% removal (conventional harvest), in two fields with a Corn-Soybean rotation and

Corn-Corn rotation. The grain and stover yield for each harvest method was recorded (Table 1.1), and machine performance evaluated. Samples have been analyzed by the Idaho National Laboratory to evaluate ethanol yield for the different constituents and USDA-ARS collaborators will assess the impact of corn stover removal on soil carbon and sustainability of different stover removal treatments.

The stover yield was approximately 3 ton/ac (Dry Mattter) for 100% removal, with the Top 50% accounting for over 2 ton/ac and the Bottom 50% less than 1 ton/ac. The estimated Bulk Density of the stover without compaction was 3 - 4 lb/ft^3. There is a significant difference in moisture content, with the Top 50% cut approximately half the moisture content for the Bottom 50% cut. Therefore, storage without additional drying may be possible for the Top 50% cut. The Bottom 50% and 100% removal material would most likely require additional processing for long-term storage. Ethanol yield tests have shown that the Bottom 50% material requires significantly greater pre-treatment than the Top 50% to obtain comparable theoretical ethanol yields.

Table 1.1 Stover Yield and estimated stover density for different harvest treatments

Field	Harvest Class	Harvest Area (ac)	Grain		Stover		
			Moisture Content	Yield (bu/ac DB)	Moisture Content	Yield (ton/ac DB)	Density (lb/ft^3 DB)
Corn Soyabean Rotation, Soybean 2004, Corn 2005 (3 reps)							
32-1	All 100%	1.7	12.26%	169.67	23.64%	3.12	3.63
32-1	Top 50%	1.7	12.36%	165.48	12.52%	2.04	3.86
32-1	Bottom 50%	1.7	13.22%	189.91	41.80%	0.79	4.04
32-1	Conventional	1.7	13.41%	205.04	No Stover Removal		
Corn/Corn Rotation for 2 years, Corn 2004, Corn 2005 (3 reps)							
E1-1	All 100%	1.0	12.10%	140.40	15.45%	2.10	3.05
E1-1	Top 50%	1.0	12.06%	139.69	11.26%	1.30	3.38
E1-1	Bottom 50%	1.0	12.86%	139.56	27.56%	0.56	3.02
E1-1	Conventional	1.0	12.86%	140.09	No Stover Removal		
Corn Soyabean Rotation, Soybean 2004, Corn 2005 (Pilot Study)							
21-INEL	Top 50%	0.3	11.56%	166.96	25.18%	2.02	3.17
21-INEL	Bottom 50%	0.3	(See above)		58.49%	0.88	3.06
21-INEL	All 100%	0.3	12.09%	160.05	41.12%	2.65	3.55
21-INEL	Conv_Cut_Hgt	0.3	11.82%	155.34	30.17%	2.08	3.21

The present prototype harvest system has major limitations in performance, primarily due to material feeding problems at the combine header, and material handling out the rear of the combine, particularly for the 100% removal. The stover harvest field capacity is less than 50% of that of conventional corn harvest. However, minor modification of the crop row header to improve header feed performance and a significant improvement of the roto-chopper and blower system at rear would substantially increase the capacity of the machine. If these issues related to material handling at the header and rear of the combine are overcome, the overall field performance of the machine would be more than acceptable. The actual combine threshing systems is able to cope with the additional stover material without modifications. Therefore, biomass harvesting would only require an additional “biomass” head and modified rear stalk chopper for use on a conventional combine. This has significant capital cost benefits.

Further analysis of the 2005 harvest data provided some insights for further development of stover harvest systems. The bottom 50% of material represented only 30% of the total dry stover harvest mass in the field and required much greater pretreatment for ethanol production. The lower cut heights also significantly reduced harvest performance. In addition, there would be significant soil erosion benefits from leaving the lower portions of the corn stalk in the field. Therefore, the Top 50% removal scenario appears as the best option since it would significantly improve machine harvest performance, provide greater protection from soil erosion and has the highest ethanol conversion potential.

The reduced harvest performance is primarily due to issues related to material handling at the header and rear of the combine. The combine threshing system is capable of handling the addition material flow due to stover harvest without modifications. This has a significant capital cost benefit, since conversion to biomass harvesting would only require an additional “biomass” head and modified rear stalk chopper.

Task 1.2 *Stover Characteristics* (IronHorse Farms)

Tasks 1.2, 2.4, 4.2, and 8.2 are all related and benefit from work completed and information generated by the specially designed corn test plots.

Per the project plan, test plots were planted in crop years of 2003, 2004, and 2005. Plots were designed to vary variety, soil moisture (irrigation), plant spacing, and soil fertility, to determine the impact of these variables on stover yield, stover composition, and soil mineral/nutrient removal (in the stover). Data collected include grain and Stover harvest moisture, grain and Stover yields under various soil types, planting dates, plant populations, row widths, tilled, no-till as well as under irrigation and dry land situations. Samples were taken from upper, middle and lower plant segments of all possible circumstances (as listed above). Grain was separated from the samples. The remaining Stover was placed in large paper seed corn bags until air-dried. Those samples that had completed the air-drying process were further processed through an electric wood chipper and re-packaged into appropriately sized bags. A random sub-sample set was selected, and these samples were then re-weighted, relabeled and shipped to Midwest Labs to complete mineral and other analysis. Soil samples were also taken and analyzed for soil organic matter as well as the next season’s nutrient needs.

A poster presentation on the preliminary findings was prepared in cooperation with Steve Thomas (NREL) and was be presented at the “27th Symposium on Biotechnology for Fuels and Chemicals” to be held in Denver, CO. in May 2005.

The abstract for that meeting is included below.

Assessing the value of a targeted corn stover harvest by understanding the distribution of inorganic nutrients

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The overall objective of this project is to establish benchmarks for the distribution of inorganic nutrients within the stover portion of the corn plant after physiological maturity. An assessment of the effects of targeting specific sections of the plant for in-field separation during a stover harvest is of particular interest. This work will identify stover harvest methods that would minimize nutrient removal, and provide potential stover cost (savings) to biomass procurement, transportation and harvest, considering changes in density, dry matter, yield and typical retail value of various nutrients. This study was designed to address this issue over a period of four years. Results from the first two years are now available and some preliminary observations will be made.
Replicate rows of five popular hybrid corn varieties were planted at three locations that have different soil types. The variables explored in this experiment include the effect of location (3 locations; includes weather patterns, soil types and available nutrients), irrigation, year, planting date (early vs. late), tillage practice (till vs. no-till), population density (normal vs. high), and genetics (5 hybrids) on the amount of several nutrients sequestered in the stover. Stover was harvested at the same time as grain and partitioned into 3 segments along the vertical axis of the plants, simulating different cutting heights and stover removal percentages. The mass of dry stover represented by each fraction for each treatment was determined, as was the moisture content of each fraction at harvest. The amounts of P, K, S, Ca, Mg, Na, Fe, Mn, Cu and Zn sequestered in dried stover fractions were determined by standard analytical methods. The amount of free sugars remaining in stover fractions was also determined. The impact of stover removal on soil quality, farming practices, and biomass processing in the context of a continuous corn farming strategy will be discussed.

Specific requests for access to this project data should be directed to Tom Schechinger at IronHorse Farms.

Task 2.1 *Storage Systems and Preservation* (Mat)
(Work done between March 1, 2003 and September 30, 2005)
The goal of this task is to evaluate the feasibility of storing and preserving corn stover biomass via ensiling, as a means to increase storage density, reduce fire risks and eliminate the need for drying at harvest time.

The experimental plan makes use of a triple cell concrete bunker to test a variety of storage conditions. Although a Triple Cell Bunker was designed early in the project, installation of this bunker would not occur until 2004. The late award of the cooperative agreement, as related to the corn harvest season, did not allow adequate time for site preparation or contractor scheduling prior to the 2003 Stover harvest. Therefore, two small temporary bunkers were constructed in 2003 to begin testing

The first small (9768 cubic feet) temporary bunker was filled with chopped Stover (no grain). The Stover was weighted and the Stover's harvest moisture established prior to placement into the bunker. Water was added and sensors (provided by INEEL) were strategically placed in the pile during the fill and compacting process. The information provided by these sensors along with additional analyses and visual monitoring provided direction and increase confidence when filling the much larger bunker in 2004. A plastic tarp was then placed over the bunker and secured.

A second bunker (11040 cubic feet) was then filled with chopped Stover using a conventional forage chopper (included the grain). The material in this second bunker was used in future months to test early component separation prototypes.

Several thousand bales of Stover were harvested using a specially design flail windrower and then baled with a John Deer Round-Baler. The flail type windrower is meant to reduce the amount of dirt involved in a normal baled Stover harvest. A significant portion of this baled Stover was gathered for filling the large bunker in 2004. About 30% of the delivered baled Stover had a tarp placed over it to reduce deterioration during storage.

The first small (9768 cubic feet) temporary bunker that had been filled with stover (stover only) in the fall of 2003 was emptied in late March 2004. Prior to removing the stover from the bunker the temperature and humidity sensors were hooked to a reader and data gathered. The humidity readings however were not able to be collected due to an apparent programming problem. As the stover was removed from the pile, sensors were retrieved and problems in the retrieval noted. Pictures as well as samples were taken and are to be analyzed. Deterioration, discoloration and moisture migration patterns were also noted. Samples for fiber tests were delivered to ISU (Molin Kuo). Additional samples were gathered and stored (in vacuum packed plastic bags) and sealed in barrels for future fiber and quality testing.

The second bunker (11040 cubic foot) was also emptied. This bunker contained a combination of stover and the grain. The grain after separation was taken to a local grain merchant and the amount of heat and mechanical damage determined.

By April of 2004, much of the bunker site preparation has been completed. An order had been placed with Wieser Concrete of Maiden Rock, Wisconsin for the precast walls and overall construction of the storage bunkers. According to Wieser representative (Phil Miller) construction could begin as early as August 9th and the first bunker would be ready for stover ensiling prior to September 30th. Arrangements had been made with Agriland Farm Service (a local farm cooperative) to provide stover from a standing harvest using equipment design modifications, provided by ISU and operated by Agriland. A standing stover harvest was anticipated to begin in late September, providing high moisture stover (70% moisture target) for storage test. Additional storage bays would include a combination of stover from 2003 baled harvest and the 2004 standing harvest and be ensiled at a lower moisture level than that mentioned above. Thomas Foust of Idaho National Engineering & Environmental Laboratory committed to supporting the stover ensiling (storage task) with acid sampling methods, monitoring equipment and the trained personnel required to operate and install such equipment. The sampling methods and acid formation information was in addition to the work completed by Midwest Laboratories in task 2.2 and would also included tests of additives that might aid in the production and longevity of the preserving acids.

Construction of the bunkers (35,080 sq. ft.), was completed in September 2004 (thus completing milestone 3 approximately 2 months early). Agriland Farm Service (a local farm cooperative) began to harvest Stover utilizing a JD9750 combine with several additional modifications and retrofitted attachments. Initially harvest was slow due in part by the typical problems involving a prototype startup. The Tornado Pulper, Hydro Shear and screw press were evaluated from a mechanical prospective and necessary repairs completed. Baled stover (from the 2003 harvest) was processed through the Tornado pulping system. Individual capacities of the systems components were noted and maximum through-put potential estimated. A portion of the processed stover generated in the systems test, was sampled, tested for moisture and place in Bunker #1. Additives such as molasses and bacterial inoculants were ordered and used on a portion of the stored stover. These two treatments were compared with un-treated stover to help identify the best and most cost effective storage practices. Stover samples (from the 2003 storage) were delivered to ISU (Monlin Kuo) for fiber analysis (Task 3).

The system used for “Whole Stalk Harvesting”, although far superior to the 2003 season, was much slower than had been anticipated (modified JD9750 combine, Photo in Figure 2.1). Draw backs included the system’s sharply reduced grain separation ability as stover moisture increased. Solutions included cutting higher on the stalk, avoiding the lower stalk (lower stalk proved to be higher in moisture). This higher than planned cut height, in turn caused less harvested tons per acre and slow overall stover collection speed to a small extent. The much larger problem was simply waiting for standing stalk to become dry enough for an adequate grain separation speed. Rain delays and slow starts on dewy mornings also caused substantial reduction in operational time. The slow operational speeds and rain/dew delays caused farmers that had earlier committed acres to the project to pull out. The “Whole Stalk Harvest” was stopped in late November. Resulting in two bunkers filled (Figure 2.2 below), one with high, 60 %(most of the water was added) moisture another with 30% to 35% moisture stover. Baled stover was harvested and placed into the third bunker. Data collected include approximate grain yields and harvest moisture, stover yields, stubble height, cob %, dry weights, pounds per cubic foot both in storage and in transit. % grain remaining in stover after combine separation, harvest moisture of stover, water added and final storage moisture. Treatments involving molasses and bacteria inoculants were tested as well, as a check. Stover samples were collected for further analysis by Mat Inc., Midwest Laboratory, and INEEL. Tarps were placed over ensiled stover and later gas samples were taken from beneath the tarps for further analysis by INEEL. Ensiled stover samples from bunker #1 (60% moisture) were made available to industry, beginning in February 2005.

Figure 2.1 Agriland Farm Service, one pass, stover harvester and collection wagon

Figure 2.2 Sealed stover storage bunker (ensilage storage)

In February 2005,Bunker #1 was uncovered and 33.92 wet ton of ensiled stover was removed. Within hours of the ensiled stover's removal Midwest Laboratory representatives had completed sampling of the remaining stover. The photo below (Figure 2.3) depicts a portion of the piles face (about one third), pop cans were temporally placed in the holes from which samples were gathered in order to demonstrate the degree of sampling. A more complete pictorial history was created and is available.

Figure 2.3 Face of sampled ensiled stover pile

Temperature was measured in each of the holes remaining after stover samples were taken. Temperatures ranged from 98 to 120 degrees Fahrenheit. Samples taken were later split (allowing two sets of the same) by Midwest Laboratory. One sample set was then shipped to INL for additional analyses. Preliminary results on samples analyzed, were presented by Corey Radtke (INL) at the “DOE/USDA Joint Feedstock Portfolio Review” in Alexandria, VA. Additionally at the same DOE/USDA review, information as to how stover was harvested, transported, and methods used in building the stover ensilage pile were presented by David Glassner (Nature Works LLC). The presentation was prepared by David Glassner (Nature Works LLC) and Tom Schechinger (IronHorse Farms Inc.). Mat Inc. was represented March 14th through the 16th at the “DOE/USDA Joint Feedstock Portfolio Review” by Tom Schechinger.

A decision was made not to construct a slurry store (DP A) as the stover completely absorbs all the moisture at the high (60%) moisture level.

In Late June2005, Bunker #1 was again uncovered and about sixty wet tons of ensiled stover was removed. On the 29th of June, Midwest Laboratory and INEL representatives were on site. The representatives took 180 individual samples from the bunkers face. Of the 180 samples, 90 were used to make up 18 composite samples which were taken back to the laboratories for further analysis. INEL representatives took another 90 samples; coordinates of these samples were predetermined by computer randomization and should help assess sample variation. The photo below (Figure 2.4) depicts a portion of the piles face (about one third); measuring tapes were temporarily taped to PVC pipe and placed in front of the area to be sampled so that coordinates could be quickly located. Additionally bulk samples were taken by INEL representatives for IOGEN and NREL’s analysis. A more complete pictorial history was created and is available.

Figure 2.4 Another sampling of material from stover ensilage trial

In late September 2005 Bunker #1 was again uncovered and approximately 60 wet ton of ensiled stover was removed. Within hours of the ensiled stover's removal Midwest Laboratory representatives had completed sampling of the remaining stover. This represented the fourth quarter sampling with stover that had been in storage for approximately one year. A large number of samples were also collected, frozen and delivered to Idaho National Energy Laboratory for additional analysis; included were larger samples planned for distribution to potential industrial converters for even further analysis.

Work from this task was presented in a poster session at the 28th Symposium on Biotechnology for Fuels and Chemicals, Nashville, Tennessee April 30 to May 3, 2006.

The abstract for the poster session is below.

Quality Changes During Bunker-Ensiled Storage of Corn Stover for the Biorefining Industry

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In many areas of higher rainfall, and particularly when using an agricultural residue, biomass may only be available at moisture concentrations above 25% at the time of grain harvest. In these conditions, wet storage may be economically advantageous over dry storage because of the large costs associated with commercial drying, and the unreliability of drying the biomass in the field. However, another possible advantage of wet stored systems is that a percentage of the in-biorefinery pretreatment may be accomplished during the wet storage, defraying the overall impact of the wet system on the minimum ethanol selling price (MESP).

The purpose of this research was to estimate the baseline compositional and relative ethanol conversion efficiencies of control and wet stored corn stover on projected biorefinery operations, and to identify areas which will most likely result in an increased payoff when further developed. Further, the costs of the wet stored system was quantified.

General Conclusions

While wet storage reduces or eliminates the risk of fire and potentially the cost of initial drying of corn stover (for dry storage), it results in other issues. Under typical harvest conditions, stover is below the ideal moisture condition for ensilage, so additional water must be added. This water may need to be removed later for processing of the stover and adds to transportation cost of the ensiled stover. Futher, a loss of structural carbohydrates (~5-20%) was observed in the course of the storage (depending on specific storage treatment), which represents a potential yield loss for

downstream biomass fuels/chemicals such as ethanol. Wet storage would most likely be cost advantageous only if further pretreatment processes could be combined with the wet storage.

Task 2.2 *Analytical Support* (Midwest Labs)
See analytical description under task 2.1 summary.
Tests conducted:
Midwest Labs

- NDF
- ADF
- Protein
- Lactobacillus
- Water extractable sugars and sugar alcohols

INEEL

- Extractable lactate
- Propionate
- Butyrate
- Acetate
- Complete quan-sach analysis

Task 2.3 *Investigate Potential Collection Centers* (IronHorse Farms)
(Work conducted between March 2003 and September 2005)
The objective of this task was to investigate western Iowa and eastern Nebraska for potential collection sites for one pass corn stover harvest, considering such factors as existing storage and transportation infrastructure, and the best modes of harvest and transport. This region was selected due to its proximity to Cargill's Blair Nebraska corn milling site; a potential location for a biomass biorefinery.

Stover Collection and Transportation:
IronHorse Farms began by gathering names and contact information on Farm Groups and Cooperatives including Ethanol Coops. Time was also spent considering & discussing the rail option with the Iowa and Nebraska Department of Transportation, as well as some smaller grain elevator operators. Although transport by rail has the potential for significant savings, concerns over timeliness, material freezing to the side of railcars and receptiveness of the larger rail-lines has been discussed.

The Coast Guard and the Corps of Engineers were consulted with as to the short and longer-term viability and dependability of barge movement on the Missouri River. Environmental issues (involved along the River), that do or may have an effect on barge traffic, were researched. Although the barge season is short on the Missouri river, the potential for dedicated or more personalized service was encouraging.

Grain and or loading facilities along local rail lines, as well as barge terminals & moorings on the Missouri River, were visited. Discussions on transportation methods (including service and satisfaction) were conducted with owners and or operators. Discussions were held with representatives from the two primary barge operations (operating north of KC Missouri) on the Missouri River. This led to Investigations of potential loading and off loading systems, availability, capacities, operational cost, equipment cost as well as preliminary operator interest. The short and longer-term viability and dependability of barge movement on the Missouri River (north of KC) was discussed with those barge operators.

Research of the transport cost and availability of adequately sized transport vessels for Rail, Barge and Truck was conducted. Preliminary conclusions provided by the investigation points toward the utilization of dedicated barge for transportation of a major portion of the anticipated one million ton of stover that would be required annually at the Blair facility. Although large nationally know rail lines are often considered very competitive for long distance transportation (i.e. like Omaha to New Orleans) they seem to lack competitiveness when considering short hauls (30 to 80 miles). Understanding that the cost of stover needs to remain relatively low ($25 to $40) in order for stover to be seriously considered for use as a feedstock (petroleum alternative), cost incurred by long hauls in any transportation system are prohibitive. This is not to say that rail is incapable of accommodating short hauls, just that rail is unlikely to. However interest among certain short line companies has been expressed. Since Blair is not served by these short lines, such a scenario would require conversion to a relatively stable product along the short line. This sugar (or what ever) could then be transported through normal rail channels. Although additional consideration should be given to rail as an option, it seems unlikely to be a serious competitor verses a dedicated barge system for the Blair facility. This would change if Missouri River navigation was seriously hampered by unrelated environmental issues or extremely low water flows.

It is possible that potential partners could further reduce cost of a feedstock for the Blair facility. Theoretically these potential partners would purchase specific components/fractions of the stover (i.e. cob, woody ring or fiber) from the producer/collection point at a higher price than average stover component. These fractions/components are used for such higher value products as chemical carriers, paper, rayon among others.

Several potential collection sites were considered. Five potential sites along the Missouri River were selected and provide a basis for an initial delivered stover cost estimate. Calculations utilizing information from experts in river transportation, ISU Farm Custom Rate Surveys, a resent producer survey completed by IHFI, 2003 test plot work completed by IHFI and past experience of IHFI, provided a high ($41.47) and a low range ($28.53). These calculations do not include a profit to the collection site itself, potential savings in cost of harvesting and tillage by farmers, effects of targeted harvesting (less inorganic collection), opportunity with the grain, nor the potential sale of higher valued components of the stover. Efforts were begun to define and calculate stover costs under various scenarios both at farm gate and delivered to converter.

Government regulation and permits were investigated, to understand if this had the potential to pose significant barriers. The specific areas of permit interest include sovereign land, mooring and conveyor support, water allocation, grain bargaining, grain warehousing, NPDES discharge, air quality, fugitive dust rule, ground water contamination, storm water run off and other issues were permits might be required. Concerns involving other potential problems such as collection point locations in or near flood plains were considered and FIRMette Maps utilizing FEMA web site were created.

Ensilage represents one option for extended stover storage. Bunker designs for ensiled material were further researched. A trip to Greeley CO. (old Monfort Feedlot) was helpful. At Greeley the bunker side walls are curved to accommodate the wheels of the packing equipment. This along with other design elements allow for more thorough packing along the bunkers edge without risking equipment rollover.

Stover production and deliver to collection sites

To research possible production volumes and harvest concerns, whole plant harvest demonstrations in Missouri, Western Iowa and Central Iowa were attended. Implications of those demonstrations were evaluated and considered. After witnessing several stover harvest seasons, it became increasingly obvious which harvest systems would most easily be accepted and capable of succeeding; whole ear forage harvest systems. Next, component separation issues were researched. Since component separation has an effect on harvest system selection and harvest cost, it is important to understand how component separation and harvest system interact.

A visual surveys was completed (in ten mile increments) as to percentage of crop-able acres planted to corn, soybeans, switch grass, wheat and other cereal grains within 20 miles of the Missouri River, in an area spanning from north of Sioux City to Nebraska City.

A study was conducted by IronHorse Farms Inc, to evaluate perceived Stover value and volume along the Missouri River as opposed to other areas such as irrigated land in Nebraska and upland farms in Iowa. Preliminary results of the survey exposed several additional advantages of corn stover collection along the Missouri River. These include a lower value placed on stover by producers in the river bottom verses the more up-land surrounding area. Less procurement, harvest, transportation cost due in part to increased acres planted to corn on the bottom verses more up-land and higher yield goals on bottom verses up-land. This survey information indicates that a potential savings of as much as 50% could be realized on the river bottom verses the cost of stover purchased on local up-land. This is possible because of additional savings and less original value perceived by the farmer as well as cost reductions caused by several factors including percentage of producers willing to sell stover, harvestable tonnage per acre and the higher density of corn acres. Research was conducted to estimate the traffic volumes as well as the impact stover collection would have on the local farm-to-market-roads as well as various federal and state highways within the proposed collection areas.

Communications & Outreach:

In the course of working on this task, IHFI produced and presented preliminary survey results in a PowerPoint presentation at INEEL (Fall 2004) (also given to Iowa's "BioEconomy Working Group" at a meeting held at the Iowa Energy Center in Summer of 2003). The presentation included preliminary information gathered during a farmer survey (survey participants were farmers operating on the Missouri River bottom from Sioux City to Kansas City). Results indicated that this survey represented 5% of the bottom-land acres between those two cities. The survey area is presently viewed by IHFI as the most promising for cost effective and advantages stover delivery to the Blair facility. Tom Schechinger also attended and participated in the "DOE/USDA Joint Feedstock Portfolio Review" in Alexandria, VA. The periodic meetings of the BioEconomy Working Group also covered issues of buyer/supplier relationships and allowed conversations with a variety of agriculture stakeholders.

Various ways of financing a biorefinery collection systems were explored with Terry Tomlinson of the "Texas Panhandle Development Project" (learn more at the projects web site www.bioeconomicdevelopment.com). The early stage methods of financing which Terry is involved with are being tested in the real world. According to Terry, the projects acceptance seems to be adequate as of now. Other financing methods are being researched.

Additional research and consideration continues on acceptable methods of valuing stover, strategies that may provide added savings and potential cover crops.

Future Agricultural trends and options:
Additional survey work was done to better understand affects of recent price trends and production fears (corn and soybean prices favoring corn production along with fear of soybean rust outbreak) on corn acreage in the collection areas being considered. Results of these surveys indicate a five to seven percent increase in corn acreage along the Missouri River Bottom. Since trends such as this will affect stover transportation cost and so on, additional research was initiated. Discussions with Kent Vickre (Iowa Farm Business) suggested that increases in the profitability of corn production is a driver of increased corn acreage but incremental comparisons (i.e. $20 added profit equals ___ percentage of increased acreage) were unknown, in his opinion.

Research and consideration as to the potential affects of non-conventional production methods such as solid seeded corn, double crop corn, the use of extremely late maturing varieties and double cross hybrids verses single cross were continued. In these scenarios the value of the crop minus production cost equals profit and remains most important. Although increases in grain yield and even stover yields are expected to continue to offer substantial reduction in production cost per unit over time, extreme changes in production methods with an emphases on the value of the whole crop verses the value of the grain seem to offer the largest potential in the short term, mostly by reducing production cost.

Meetings with extremely large (by local standards) farming operations demonstrated how and at what speed production agriculture is changing. The changes noted will allow quicker response to the needs of a biorefinery and simplify the logistics and organizational needs of a large scale collection effort. More flexibility will be available due in part to equipment leases rather than outright purchases, much larger and more business oriented farm operations (which include business managers, operational design, procurement and marketing staff) and also more ability (due to increased sophistication) to raise investment capital for advantages in vertical integration.

Conclusions:
An infrastructure does not yet exist for collection and transportation of stove quantities sufficient to supply a commercial scale biorefinery. However, upon analysis of factors in a selected target geography, it appears that there are no insurmountable hurdles to production, collection and transportation of sufficient quantities, provided that the farmer can do so profitably at a price acceptable to the biorefinery. Additional research will probably be needed in the areas of stover collection and storage, to reduce cost and time of stover harvest and provide improved storage options.

Task 2.4 *Distribution of Dry Weight in Stover* (IronHorse Farms)

See Task 1.2 summary.

Task 3 *Effect of Stover Storage on Fiber Quality* (ISU)

The purpose of this task was to determine if ensiling of corn stover results in significant degradation of structural carbohydrates. Samples were taken from the storage bunkers at the MAT, Inc., Harlan, Iowa at 3-month intervals and analyzed for changes in chemical composition and fiber strength properties. MAT Inc. started a wetter storage method after the 2004 harvest, thus samples are classified into A (drier) and B (wetter) groups. A significant decrease in tensile and burst strength of pulps was observed (compared to starting material). B series samples seem to have higher acetone solubles and lower 1 % NaOH solubility than A series samples. Accumulated results are summarized below:

A. Solubility

Storage (months)	0	A3	A6	A9	A12	A15	A18	B3	B6	B9
Moisture (%) as received:	30.43	38.24	51.00	51.48	48.46	58.56	42.87	61.53	65.33	38.64
PH	7.14	5.43	5.63	4.95	7.25	6.07	6.04	4.89	4.80	5.11
Hot water solubles (%)	13.63	12.04	16.98	9.62	8.70	9.57		16.65	15.33	
Acetone sol. (%), succ.	1.62	1.28	4.30	3.08	2.79	3.74		10.44	10.39	
1% NaOH solubles (%)	56.68	55.95	54.11	56.83	61.87	57.24		50.70	50.00	

B. Composition of extractive-free materials

Storage (months)		0	A3	A6	A9	A12	A15	A18	B3	B6
Cellulose										
Content (%)	40.89	43.21	40.42	40.78	44.21	43.39		40.31	40.26	
Degree of Poly (DP)		1843	1651	1615						
Hemicelloloses (%)		29.06	27.06	29.58	29.34	23.18	26.51		26.19	25.53
Lignin (%)		18.24	17.90	19.50	19.58	18.81	18.63		20.08	20.37
Ash (%)		3.40	3.35	4.72	4.95	4.90	4.39		6.60	6.66

C. Pulping and Pulp Quality

Storage (months)		0	A3	A6	A9	A12	A15	A18	B3	B6
Pulp Yield (%)	46.44	39.58	45.72	44.54	44.30	47.42	47.35	39.38	41.47	
Rejects (%), non-fibrous		4.99	6.78	3.91	4.04	4.70	3.12	2.50	5.02	3.32
Kappa Number*		7	6	6						
Tensile Index (N.m/g)	33.59	20.62	26.64	20.92	24.46			22.20		
Tear Index (mN.m2/g)		5.35	3.47	4.69	5.23	5.27			3.95	
Burst Index (pKa. m2/g)		1.68	0.81	1.12	0.50	0.88			0.61	

* Kappa No. multiplies 0.15=percent (%) residual lignin in pulp.

This task was terminated before analysis of the final sets of samples owing to loss of DOE funds in FY2006.

Task 4.1 *Plant component Separation* (Mat)

The objective of this task was to design, build, and evaluate plant part separation systems capable of removing contaminants and separating components of the corn plan (e.g. grain, cob, stalks or stalk fractions, etc.).

To minimize cost and time, prototype systems were designed and tested where possible by modification of current commercial equipment for processing of agricultural materials. Tests were done on fresh stover materials as well as materials removed from the ensilage bunker at quarterly intervals.

A Hay system was located, modified to improve its capabilities with corn stover and then installed. A dry pre-screening process (for dirt and sand) was purchased, installed and evaluated, as was a used chip washer. An older series JD combine, retrofitted with special equipment has been purchased. This unit is capable of harvesting stover into a dump wagon in tow while separating the grain from the cob in the conventional way. A prototype foreign material (rock or steel) air separation systems was also installed and tested. Work has begun on a prototype cob separation system. The screen separation system (woodchip screener) previously installed, was removed from the separation line and believed inadequate and prone to plugging. Other components of the stationary separation system are being considered, operated and or improved upon.
A prototype air separation system, design and built by Mat Inc. was used to separate grain and cob from the bulkier stover. The combine was used to separate the grain from the cob pieces after the initial air separation. Material for the test came from bunker #2 (grain/stover combined). With the

systems tested to date Mat Inc. personnel have concluded that total or complete separation of the cob from the remaining high moisture stover would be difficult at best. When separating wet stover components, a portion of the chopped stalk will inevitably be the same density and size as the cob pieces attempting to be separated. However contacts from two companies (Green Products of Conrad, IA and Scott Equipment Company of Hutchinson MN) indicated that they may have equipment which would be capable of accomplishing an acceptable cob separation under wet conditions.

If the stover were dry, as could be the case in a late season standing harvest or a dry baled harvest, a difference in density and near complete separation is possible. As was the case with the corn picker of the past, if the grain were still attached to the cob (an ear of corn) the density and size differences allow for separation, even when wet. In such a scenario, ears are separated from the remaining stover then grain can be shelled from the ear; at which point the cob separation utilizing air, screen or a combination is not only possible but widely practiced in the seed corn industry.

Samples of separated pith as well as pith and fiber combined were analyzed as to their value as a feed ingredient by Jacqueline Wenke (Cargill at Sioux City, IA). This analysis should help establish a dollar value for pith as a by-product and the feasibility of separation for such a purpose.

<u>Conclusions:</u>
Ensilage of corn stover combined streams (stalk with cob and grain) presents technical challenges for component separation. For separation of dry components, current technology exists for effective separation and processing.

Task 4.2 *Component Separation* (IronHorse Farms)

See Task 1.2 summary.

Task 5 - *Automation* (Mat)

The focus of this task was development of automation equipment for stover loading./unloading and sampling at the Harlan IA facility. Owing to changes in business focus by MAT and loss of DOE funds for FY 2006, minimal work was done under this task. Several design options were evaluated and several small scale tests were completed, but no full scale automation was implemented.

Task 7 *Fermentation Development* (NatureWorks)

The major thrusts of this task were:

1) Characterize baseline fermentation performance of biocatalysts and understand how to optimize the fermentation
2) Validate fermentation at pilot scale and determine feasibility of scale-up
3) Enhance biocatalyst performance via improved utilization of biomass sugars and increased tolerance to hydrolysate

The task further included: development of analytical methods for characterization of hydrolysate composition and fermentation products, and construction of a 20 L pilot fermentation system for pilot scale studies.

<u>Baseline fermentation performance and fermentation Optimization</u>

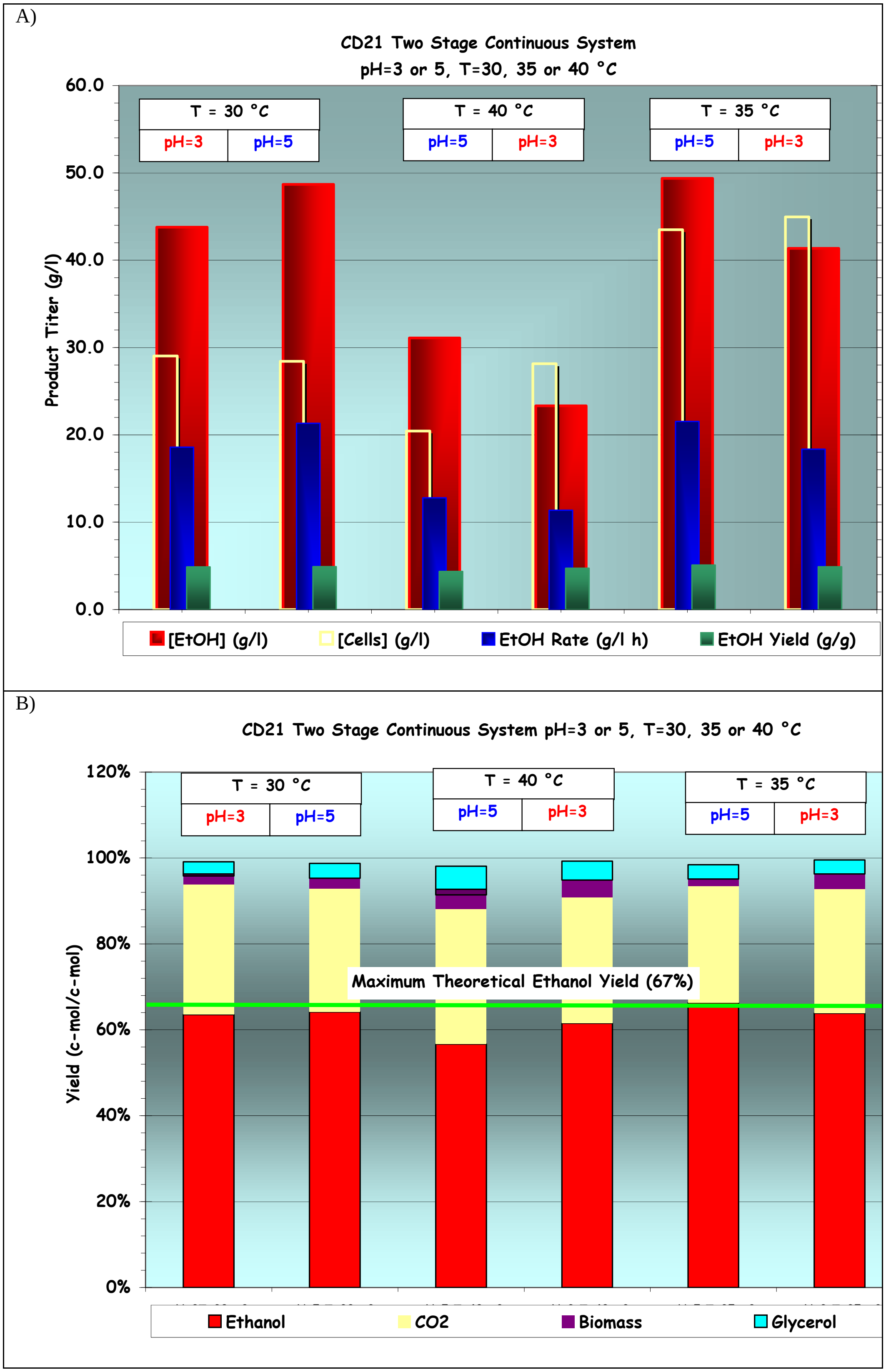
Continuous fermentation

(a) Advantages and problems with continuous fermentation. Continuous fermentation operation offers several advantages over batch operation, both in terms of fixed and operating costs, as well as in terms of the overall operational logistics. Continuous fermentation eliminates the labor and materials associated with seeding batch fermentations. It also provides a consistent and constant source of broth to downstream processing. Fermentation volumetric rate is also higher resulting in a lower fermentation volume requirement which reduces capital costs. In this work, several hurdles were overcome in terms of continuous operation, and we have demonstrated the feasibility of converting glucose to either ethanol or lactic using a continuous process. One outstanding issue is continuous operation for long period at steady state, i.e., with constant rates, yields and product titer. Previous results have shown oscillatory behavior by the biocatalyst in a continuous culture, particularly under hydrolysate like fermentation conditions. Over time, a general loss of lactic acid productivity was also observed. Many experiments have been done to characterize the performance in an effort to be able to understand the observed performance. The key finding to date is that the continuous culture selection process results in low- or non-lactic producing sub-populations over time. Experiments are now directed towards understanding this phenomenon at the molecular level. The new results are expected to guide future strain engineering efforts for developing strains that are more compatible with continuous operation.

(b) Aeration requirement for growth and production. Cell generation for CD's biocatalyst requires oxygen. CD has been researching medium formulations with the objective of eliminating or reducing the need for oxygen during growth. Medium components have been identified which support anaerobic growth of CDs biocatalyst. However, the growth rate is only about 10% of the biocatalyst rate when oxygen is not limiting growth.

(c) Detailed physiological characterization of our host biocatalyst. The goal was to understand the host biocatalyst so that CD can understand the following: 1) the effects of genetic changes, 2) the strengths and weaknesses of our host strain, and 3) our operating limits. Experimentation was focused on evaluating continuous fermentation performance as a function of temperature, pH, medium components, and dilution rate. Figure 7.1 below shows rates and yields for production of ethanol from glucose as a function of temperature and medium pH. The data show excellent ethanol yields at 35° C or below and generally better rates at pH=5. However, the biocatalyst is fairly robust over a range of conditions relevant to ultimate commercial production.

A)


CD21 Two Stage Continuous System
pH=3 or 5, T=30, 35 or 40 °C
Product Titer (g/l)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
T = 30 °C
pH=3
pH=5
T = 40 °C
pH=5
pH=3
T = 35 °C
pH=5
pH=3
[EtOH] (g/l)
[Cells] (g/l)
EtOH Rate (g/l h)
EtOH Yield (g/g)

B)

CD21 Two Stage Continuous System pH=3 or 5, T=30, 35 or 40 °C
Yield (c-mol/c-mol)
120%
100%
80%
60%
40%
20%
0%
T = 30 °C
pH=3
pH=5
T = 40 °C
pH=5
pH=3
T = 35 °C
pH=5
pH=3
Maximum Theoretical Ethanol Yield (67%)
Ethanol
CO2
Biomass
Glycerol

Figure 7.1. Characterization of CD21 in 2-stage continuous system on synthetic salts medium with glucose as carbon source. A) Ethanol titers, rates and yields together with corresponding cell densities at various pH and temperature values. B) Corresponding carbon distribution between growth and measured byproducts.

Batch fermentation optimization (lactic acid production):

As noted above, organism stability in continuous fermentations have been a problem, so the majority of work on this task has been focused on batch fermentation; which is likely to be method used for initial commercialization of the technology. Batch fermentation optimization was done with lactic acid producing strains; because there were of highest commercial priority for NatureWorks and we expected the learnings to be directly translatable to ethanol work.

Early work demonstrated that defined medium was sufficient (no growth limiting nutrient deficiencies) and that batch fermentation protocols were repeatable and highly productive relative to known alternate protocols. A number of baseline strains were characterized to identify any that were significantly higher performers than others with respect to rate, yield, titer and by-product profiles.

Genetically engineered strain 1184 derived from the organism S1 was selected for optimization studies. This strain was genetically engineered such that the majority of the carbon flux was directed to L-lactic acid.

Prior fermentation work with this strain has shown strong performance. Nevertheless, significant improvements in conversion rates and yields were necessary in order to achieve internal milestones. The fermentation optimization approach involved a series of cultivations carried out in bench-top bioreactors operated in batch or fed-batch mode.

The design-of-experiments (DoE) approach was utilized in order to systematically explore the effects of key fermentation parameters on process performance, as well as identify conditions that would allow achieving milestone targets. A factorial design of experiments was used in order to minimize the number of experiments to be carried out involving 5 variables (temperature, aeration rate, inoculum size, pH, operating mode – i.e. batch vs. fed-batch).

Figures 7.2 and 7.3 are given as examples of the type of information derived from such of experiments. Figure 7.2 illustrates the 2-dimensional correlation of lactic yields on sugar vs. temperature and oxygen uptake rates. Similarly, Figure 7.3 illustrates the correlation of lactic production rates on pH and oxygen uptake rate. The goal of DoE analysis of these experiments is basically to elucidate the statistically significant effects of these fermentation conditions on key responses (yi), i.e. lactic titer, rate and yield. Then, models are constructed, yi = f(x1, x2, …, xj) for each response yi as a function of all experimental variables xj (e.g. temperature, pH, OUR etc.). The end result is a set of equations that describe the variation of key responses within the design space. For each response, a statistical analysis was done to understand which factors, and two-factor interactions, were deemed significant. Based on the statistical resolution (a function of the number of runs), we can consider the three primary (linear) terms, the three two-factor interaction terms (e.g. T, pH), and the three quadratic terms (e.g., OUR2). Analysis of variance (ANOVA) was used to select those terms that are justifiably included in the model, relative to the noise in the data. In general, the data evaluated in this report is of high quality: (1) there are no statistical outliers according to outlier t-tests, and (2) many of the responses give a good predicted-versus-actual trend (measured by the model R^2). The models generated can therefore be used to navigate the design space and suggest experimental ranges for the next optimization round. Based on the statistical model formed from this data, we can then extrapolate to values outside this range to find a new, better, operational optima for achieving a desirable performance.

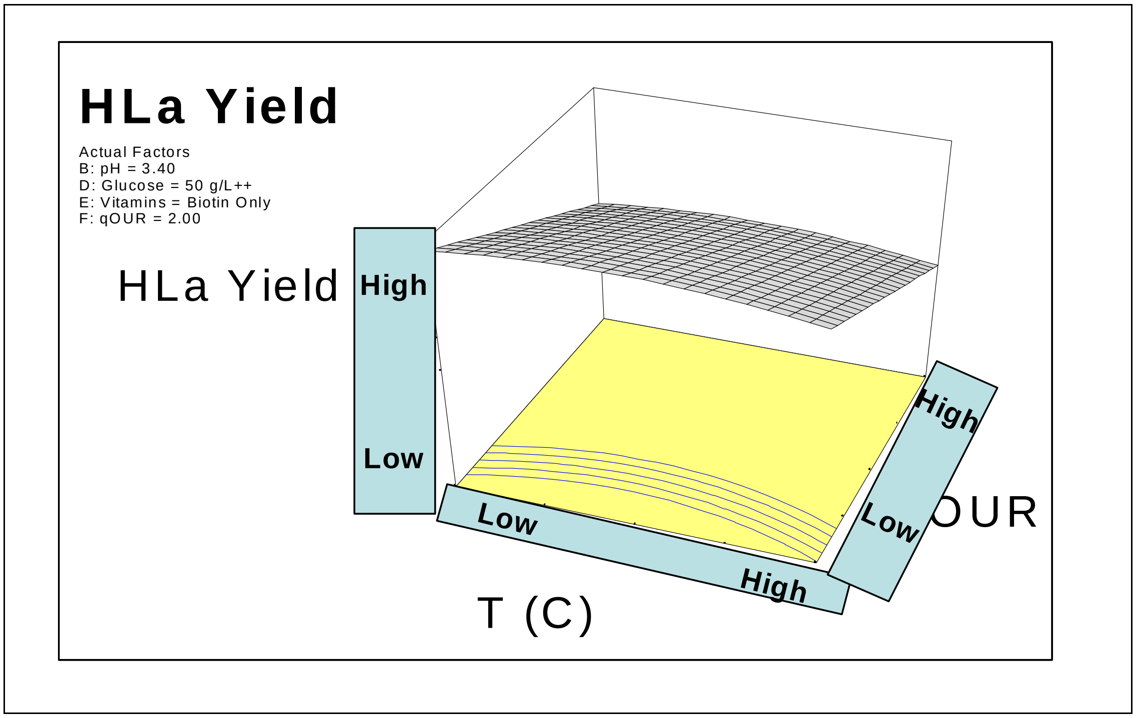


Figure 7.2. Design of experiments (DoE): effect of fermentation temperature (T) and oxygen uptake rate (OUR) on lactic yields on glucose.

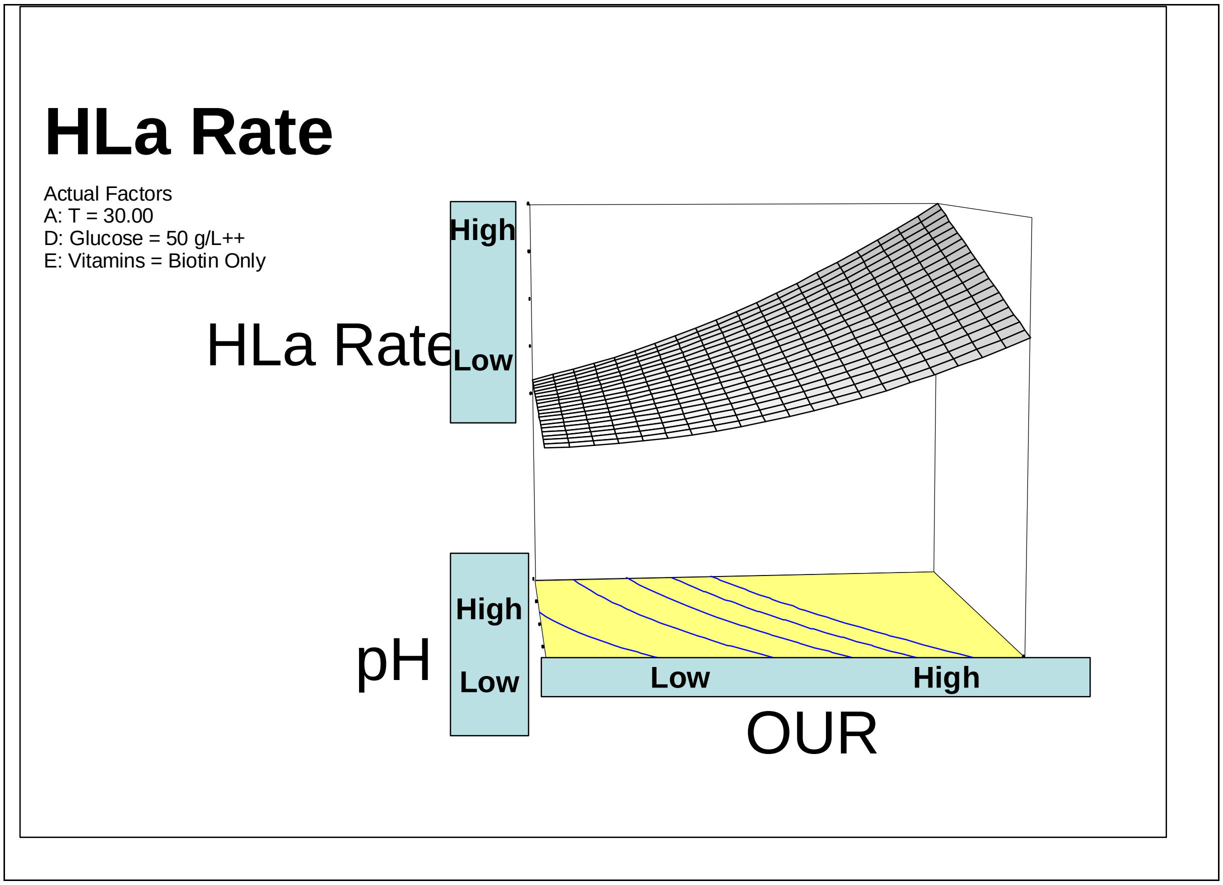


Figure 7.3. Design of experiments (DoE): effect of fermentation pH and oxygen uptake rate (OUR) on lactic production rates.

A key outcome of these fermentation optimization efforts was that it enabled us to meet the September ’05 (internal) milestone. This was achieved using a fed-batch fermentation process where the glucose was monitored online and controlled at a certain constant value. Other operating parameters, such as temperature, oxygen transfer rate, media composition and inoculation procedure were chosen based on findings of the DoE optimization studies. Figure 7.4 summarizes the key performance characteristics of the fermentation process that achieved this milestone.

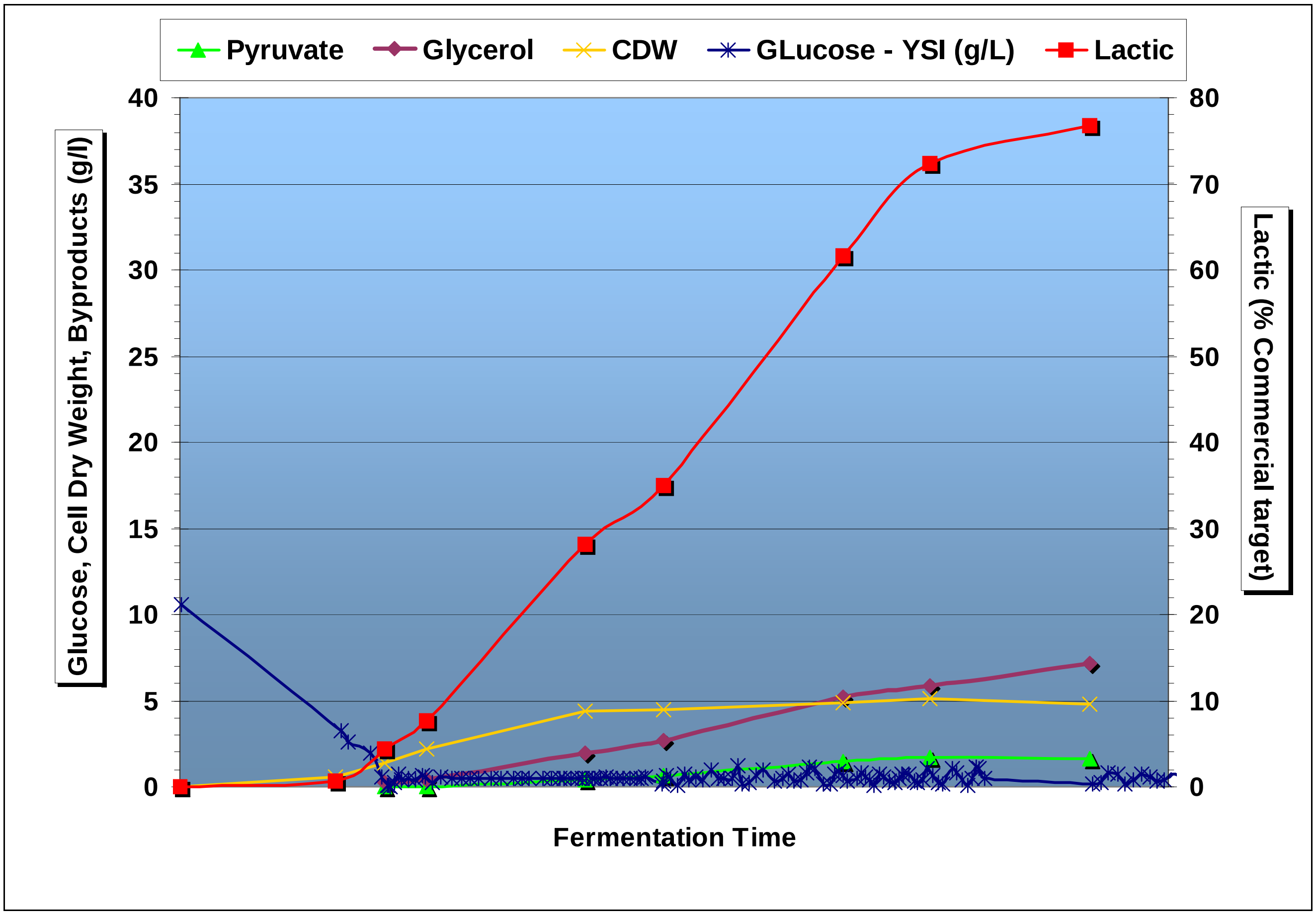


Figure 7.4. Batch fermentation with S1-derived strain 1184 that achieved the September 2005, internal milestone.

Following the achievement of the above results, new strains were genetically engineered and became available. Optimization studies were repeated with a new strain 2256. The internal June, 2007, fermentation targets were achieved using a batch fermentation process where key operating parameters including temperature, media composition and inoculation procedure were chosen based on findings of the optimization studies. The results are shown in Figure 7.5

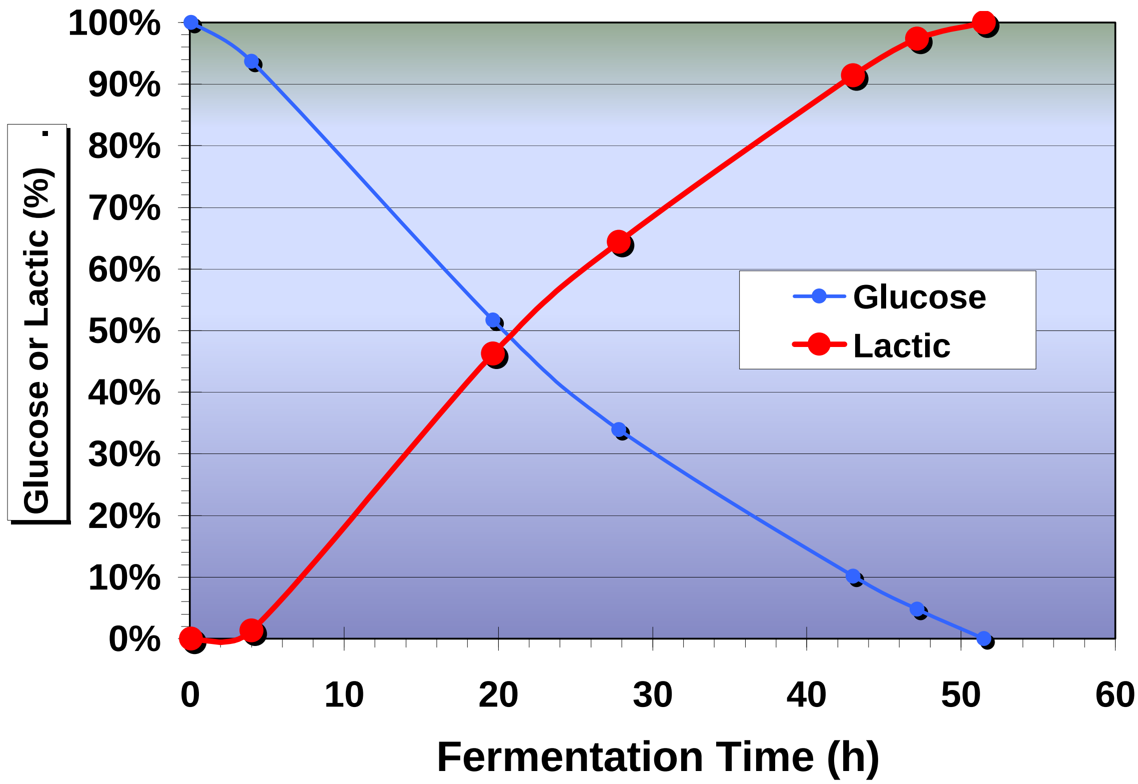


Figure 7.5. Batch fermentation with S1-derived strain 2256 that achieved the June 2006, internal milestone.

Additional performance improvements were observed for the remainder of the project as improved biocatalysts became available and the above optimization strategies were applied.

Neutral pH lactic acid fermentation process scale-up

Commercial production of lactic acid is currently generally done with a bacterial biocatalyst at neutral or only slightly acidic pH values. This study was designed to evaluate the feasibility of utilizing our new biocatalysts in a conventional lactic acid process. This work was based on the genetically engineered strain 587 derived from the organism M1. This strain was engineered such that the majority of its carbon flux was directed to lactic acid production vs. ethanol for the parent strain M1.

Prior fermentation work with this strain has shown strong lactic acid production performance at neutral pH using a two phase batch fermentation protocol on defined salts media. Nevertheless, significant efforts were still necessary in order to further develop this system such that it can be implemented in our industrial process, using existing equipment and commercial media, as well as media byproduct constraints. The fermentation optimization approach involved a number of parallel efforts, some carried out in flasks and others in bench-top bioreactors operated in batch mode.

This is a two phase process where the cells are first propagated under fully aerobic conditions to generate sufficient cell biomass, followed by an oxygen limited phase where the culture ferment available sugars to lactic acid (see Figure 7.6).

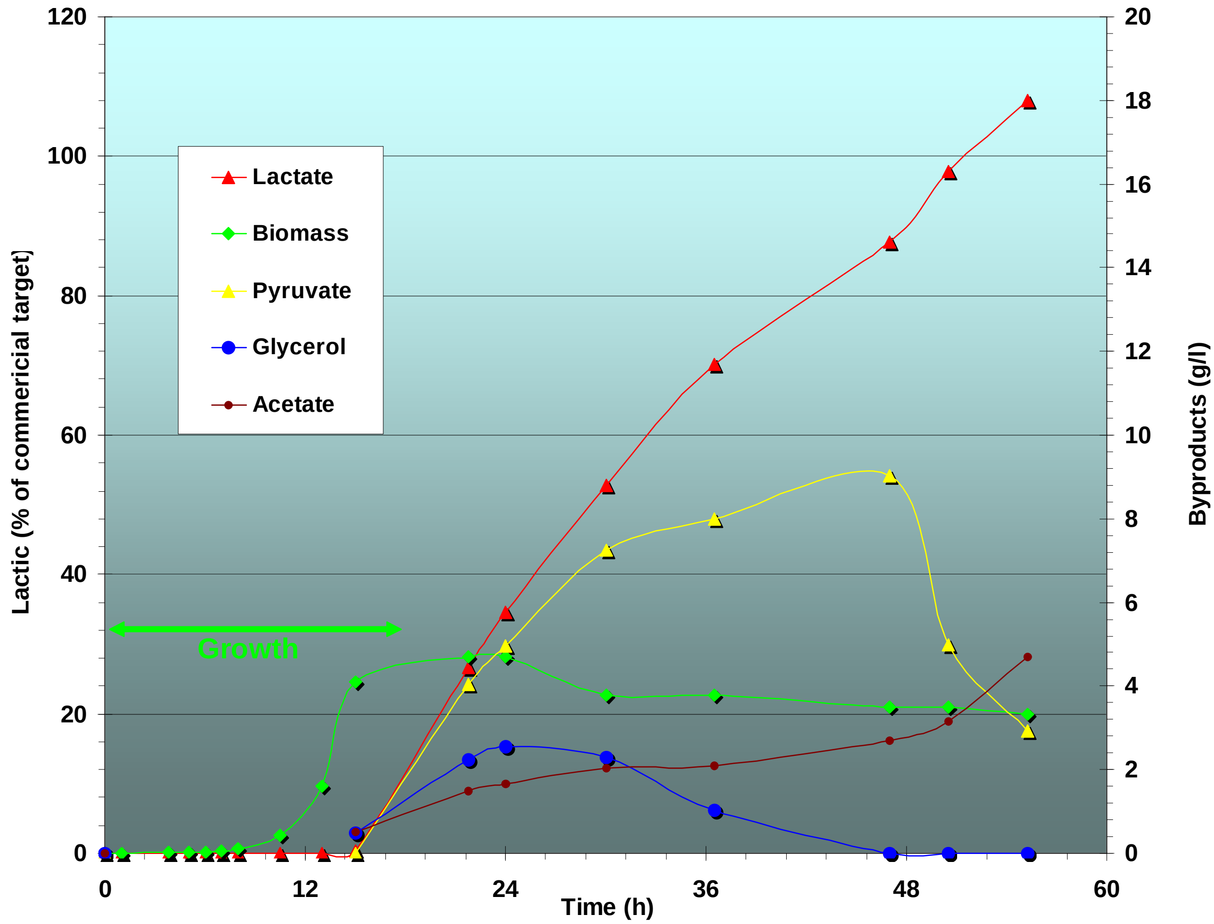


Figure 7.6. Batch fermentation characteristics using the two phase aeration protocol and plant base media.

Optimization of the fermentation process for plant production of lactic with the 587 strain has focused on fermentation conditions (pH, temperature, aeration), media optimization (e.g. nitrogen source, carbon source, vitamins, neutralizing base, etc.) as well as fitting the process into the existing fermentation facility with the current state permits. Part of the aim was to investigate media that the plant currently uses (e.g. carbon and nitrogen sources), as this can reduce raw material cost as well as simplify handling logistics and eliminate need for process modifications.

This work demonstrated that raw materials currently in use at the plant can be utilized for this process, and their optimum levels were identified. Furthermore, optimum operating ranges for temperature, pH and aeration were also established. Byproduct profiles were established, and approaches to minimize the most critical byproducts were investigated.

For example, the fermentation plant to be used for the industrial scale production currently operates under an air permit plan for the state. Measurement of off-gas from strain 587 fermentation by GC showed ethyl acetate was produced in amounts that are too high under the current permit. Laboratory experiments showed that elimination of one component from the media reduces the ethyl acetate production in Strain 587 by as much as 10 fold.

In addition, schemes for generating biomass seed using existing fermentation equipment were investigated at lab scale.

Conditions have been verified in the 20-L pilot plant for a 2-phase production scheme that give rise to satisfactory Lactic acid titers, lactic rates and production phase yield from dextrose.

Pilot scale fermentation validation and scale-up feasibility

Scale-up work was initiated in the 2006 with the objective of developing information that will lead to successful commercialization of the yeast technology for lactic acid and ethanol production. Components of the project include fermentation development and seed propagation. Initially the scale-up target is a 300,000-gallon fermentor at our Blair, NE facility. A yeast fermenting dextrose to lactic acid is the initial step to reaching commercialization on hydrolyzates. This trial provided feedback on the fermentor requirements for gas mass transfer, heat transfer and pH control. Initial changes to the fermentor were made and the trials measured performance of the biocatalyst with the engineering utilized. Fermentation development and seed propagation activities will support all future scale-up and commercialization activities including the planned scale-up on hydrolyzate in Abengoa's pilot plant.

The full scale-up project includes a biocatalyst development and an engineering and construction activity which are outside the scope of this contract. The two project components within this contract are the following:

a. Develop a lab scale fermentation process run within the constraints of the Blair facility.
b. Development of seed propagation protocol using a toll producer. The Blair facility as configured does not support yeast propagation

a) Fermentation Development

To date, the fermentation development work has been performed under conditions optimized for the low pH yeast process. The plant scale-up trial was performed while the current process is operating. That required the yeast process to operate with the same media composition as the plant process. Additionally, the temperature optimum used for the yeast in the lab is lower than what can be achieved in the plant due to cooling efficiency limitations. Pilot trials were conducted to evaluate the performance of the low pH yeast operating within the constraints of the plant process. Only minor performance issues were observed. The low pH yeast strain can perform within the plant constraints sufficient to evaluate the engineering of the fermentation system.
A second set of trials with an alternate mixing/gas mass transfer design showed results similar to the 1st set indicating a scale difference resulting in sub-optimal end of fermentation performance. Further trials are planned and will be conducted post termination of this project with increased power input and alternate designs throughout 2007.

b) Seed Propagation

The current seed train system in Blair is anaerobic. Conversion of the vessels to full aeration for yeast propagation would require a substantial capital investment. As an alternate, production of yeast seed was done in tolling facilities with the capacity to produce the seed for the plant trials. The yeast was grown, concentrated, and shipped to Blair for the plant trials. A project was completed in the Cargill-Eddyville lab to develop a process and a toller, was selected to produce the seed material.

Improved utilization of biomass sugars and increased hydrolysate tolerance

Ethanol Production from Biomass Sugars

The overall objective of this task is to develop fermentation parameters within the constraints of industrial ethanol processes. The initial work involved characterizing the existing strain(s) in fermentors, developing protocols to adapt the yeast to actual hydrolyzate solutions and doing a limited survey of the hydrolyzate tolerance of leading strains. A micro-aerobic single phase protocol was developed to give satisfactory performance on a representative mixture of xylose and dextrose in shake flask (100 rpm, 50 ml in 125-ml baffled flask, 37° C) based on advice from consultants such as Fred Keller (formerly with NREL) and current NREL personnel. Lab scale fermentation systems were established (head-space air flow, approximate OUR of 1 mmol/l/h) for the continuous adaptation to hydrolyzate. Addition methods for the analysis of key components (xylose, glucose, ethanol, acetate, HMF, furfural, etc) in the fermentation were established and validated.

In complex media, ethanol rate, titer and yield were benchmarked using mixed sugars in shake flasks and batch fermentations. Rates are reasonable in complex media, but have been poor on defined media. Buffering and pH control have been identified as likely solutions.

Two prototype M1 xylose to ethanol fermenting strains previously developed at NatureWorks were compared (DOE Contract DE-FC36-02ID14349). One of them had a better specific xylose uptake rate and was chosen for further studies. A prototrophic derivate of this strain was developed under Task 2 of NatureWorks Biorefinery project (DOE Contract DE-FC36-03GO13145/04-03-CA-70372). Its performance was evaluated in this project and was found to be similar to the parent strain. This strain was called M1-prototype1 (M1-PT1) and used in all studies below.

Acetic acid and corn stover biomass hydrolyzate (produced at NREL/Abengoa 2005) were tested for inhibition against a chosen M1 strain. Growth in media consisting of 10% hydrolyzate by volume was achieved after a moderate lag. No growth was observed after 4 days on 15% hydrolyzate. Acetic acid concentration of about 30% of maximum expected in a glucose/xylose media inhibited growth about 1/3 while 50% of maximum inhibited growth 2/3. Media with a higher concentration of acetic acid essentially stopped growth.

Initial evolutionary approaches focused on improving growth on xylose in defined media. Initially growth was poor on xylose defined media, even in aerobic shake flasks. Various sequential transfer methods yielded an adapted strain. Additionally, a low glucose/xylose chemostat was operated and yielded a strain which seems to grow better on xylose.

<u>Baseline Performance</u>
Baseline methods for shake flasks and batch fermentations were established on complex media.

Shake flask: Figure 7.7 shows a typical strain M1-PT1 mixed sugar shake flask profile.

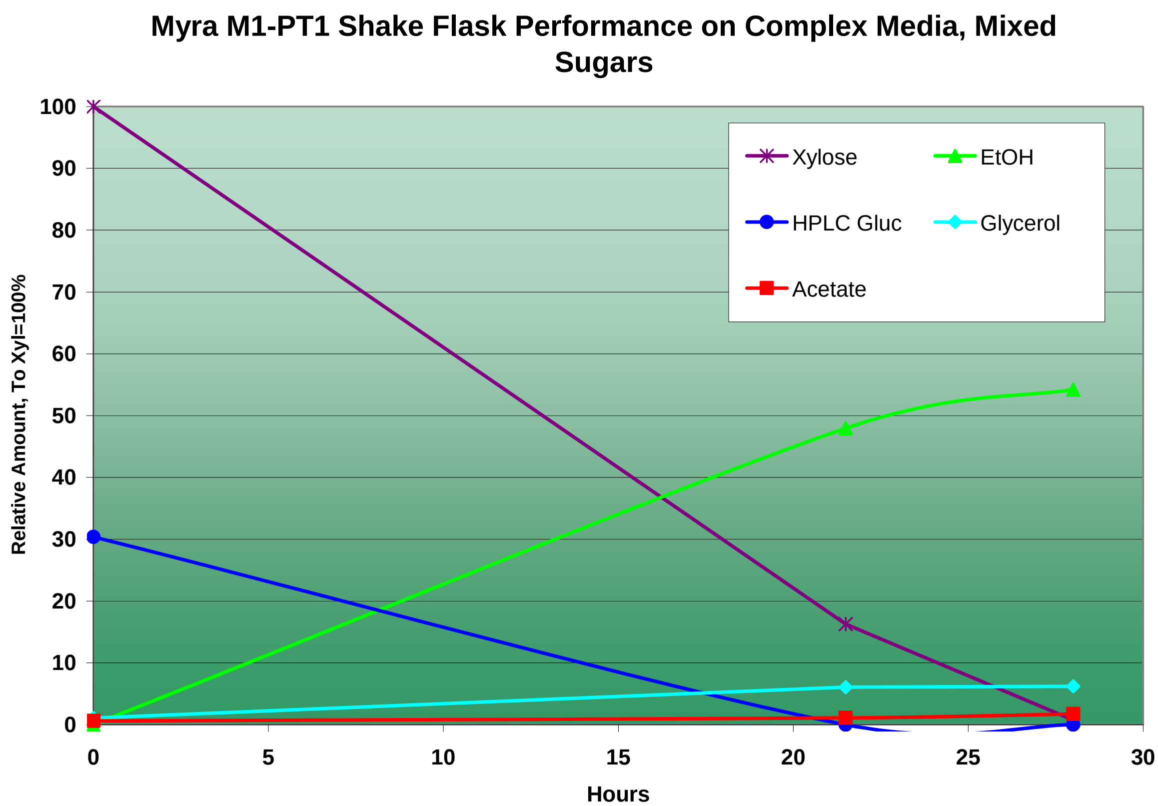


Figure 7.7 Mixed sugar shake flask fermentation

Batch Fermenters: Figure 7.8 shows a typical Myra M1-PT1 mixed sugar fermenter profile. Via Evaporation/stripping, ethanol is lost at a significant rate at the end of the fermentation, and likely is occurring during production. This would serve to underestimate titer, rate, and yield values.

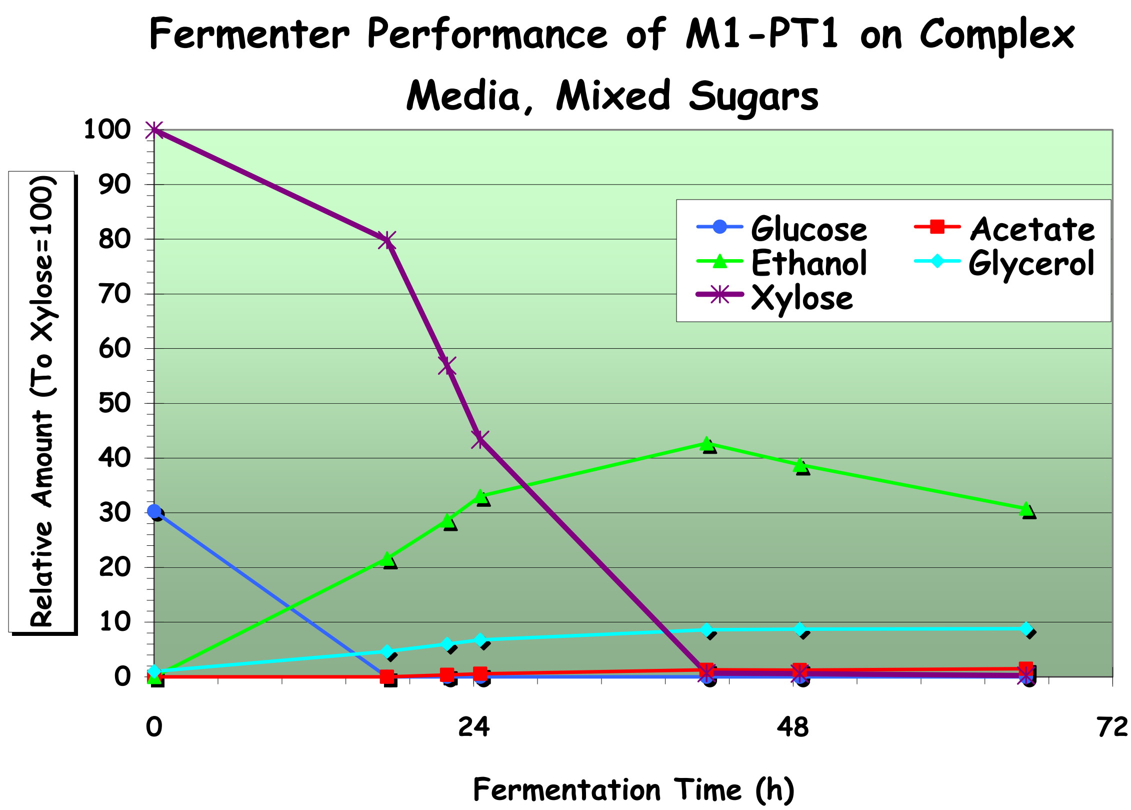


Figure 7.8 Mixed sugar trial in pilot fermentors

Performance on defined media

Strain M1-PT1 did not complete sugar utilization in defined media. The pH was identified as the key actor. Defined media does not buffer well as compared to the complex media. Initial results on dextrose media have been very favorable. Validation in mixed sugar systems is on-going.

Growth on xylose

Strain M1-PT1 readily grows in complex media with xylose as the sole sugar. On defined media, an extended lag is observed. A program was initiated to repeatedly transfer shake flasks to attempt to obtain an adapted strain which would grow in defined media xylose. Several methods including serial transfer after lag and weaning from complex media xylose to defined media xylose were employed. Many of the methods resulted in ready growth in defined media xylose. Such adapted versions of strain M1-PT1 were stored for use in further work.

A defined media chemostat was set-up and operated for 69 days under xylose limitation. Progress was gauged by monitoring steady state xylose concentration and by periodic characterization of isolates. Single cell isolates were captured and characterized in a batch fermentation at three points during the evolution. At each isolation point, the measured xylose consumption rate was higher than the previous point. The final isolate exhibited a >50% improvement in the xylose fermentation rate.

Additionally, intracellular metabolite analysis of the parent strain and the final isolate was carried out. The analysis of the parent strain showed several metabolites accumulating to very high levels, which indicated specific bottlenecks in the xylose utilization pathway. The final chemostat isolate showed substantially reduced metabolite accumulation. This suggests that the xylose utilization pathway has evolved to achieve an improved balance of enzyme activities. However, there were still a few metabolites that remained at higher than expected levels even after evolution. This analysis leaves us with specific genetic targets to potentially make even more improvements to the already substantially improved strain.

Three generations of improved strains were evaluated for improved performance versus the parent strain. Substantial (>50% rate) improved performance by the third generation strain is shown in Figure 7.9.

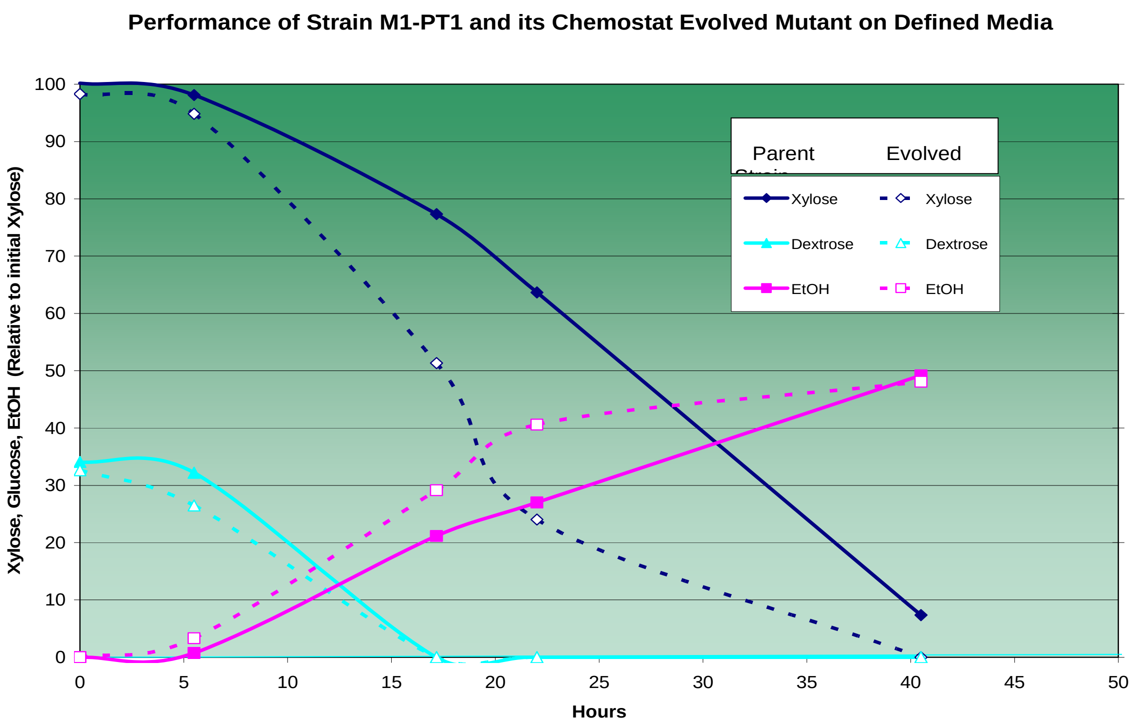


Figure 7.9. Chemostat evolution for Improved xylose utilization.

Acetic Acid inhibition

Strain M1-PT1 was tested for acetic acid inhibition. Acetic acid at about 30% of the expected maximum and pH 4 was found to significantly inhibit growth and resulting ethanol production. The primary effect is on biomass formation, not conversion of glucose/xylose to ethanol. Figure 7.10 shows the inhibition effect of acetic acid on overall performance.

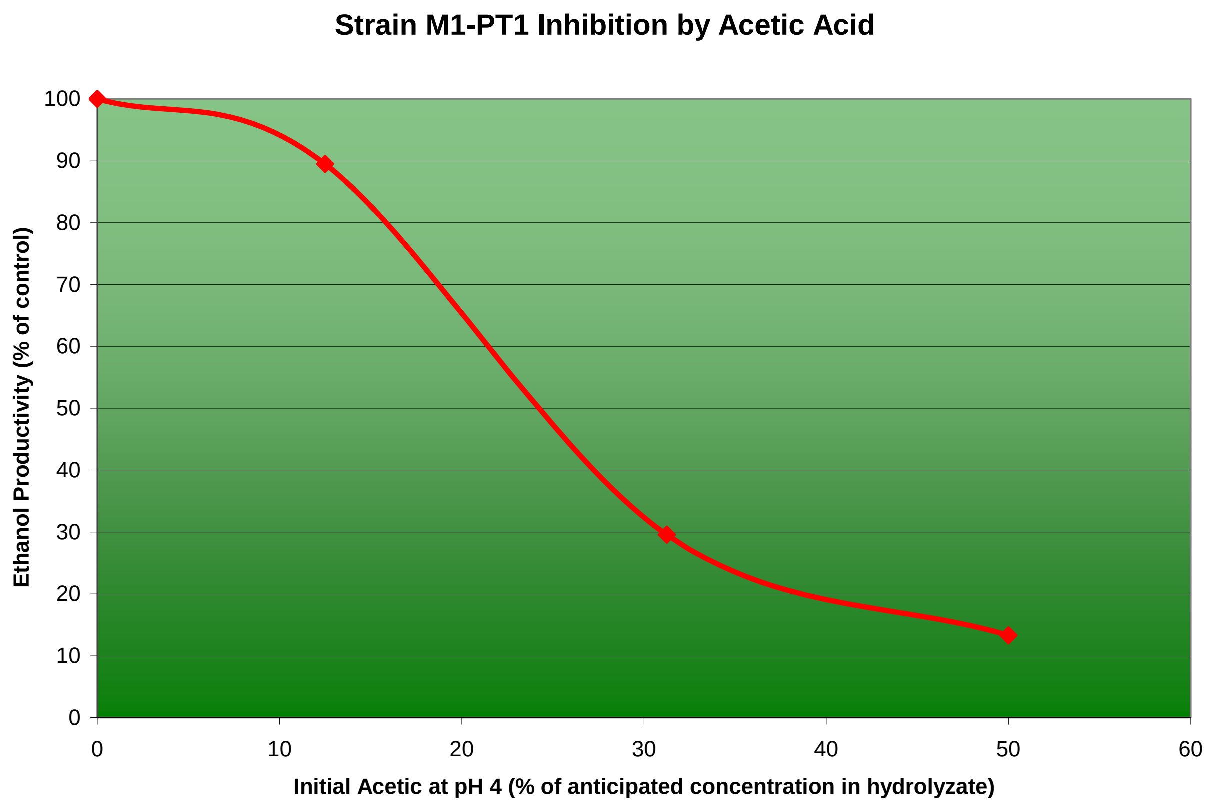


Figure 7.10 Acetic acid inhibition

A defined media chemostat was set-up and operated for 40 days, at pH=4, on a combined glucose/xylose feed, augmented with 1.5 g/L acetic acid. The system was designed to run under sugar limitation, however the acetic acid was sufficiently inhibitory such that true sugar limitation was never achieved in the system.

Isolates collected at the end of the run were characterized (in batch fermentation) for xylose fermentation in the presence of acetic acid, and for xylose fermentation in the presence of hydrolyzate. These chemostat isolates were not improved over the parents. The serial shake flask adaptation to increasing levels of hydrolyzate proved to be a more promising approach.

Hydrolyzate Tolerance

Corn stover biomass hydrolyzate was prepared for this project at NREL in the summer of 2005. This material was spiked at various levels into media to test for inhibition. With 10% of the media volume from hydrolyzate, growth was initiated after a moderate lag (Figure 7.11). As with the acetic inhibition described above, the primary effect appeared to be on growth. 15 g/L ethanol was produced. At 15% and higher concentrations of hydrolysate, no growth was observed after four days.

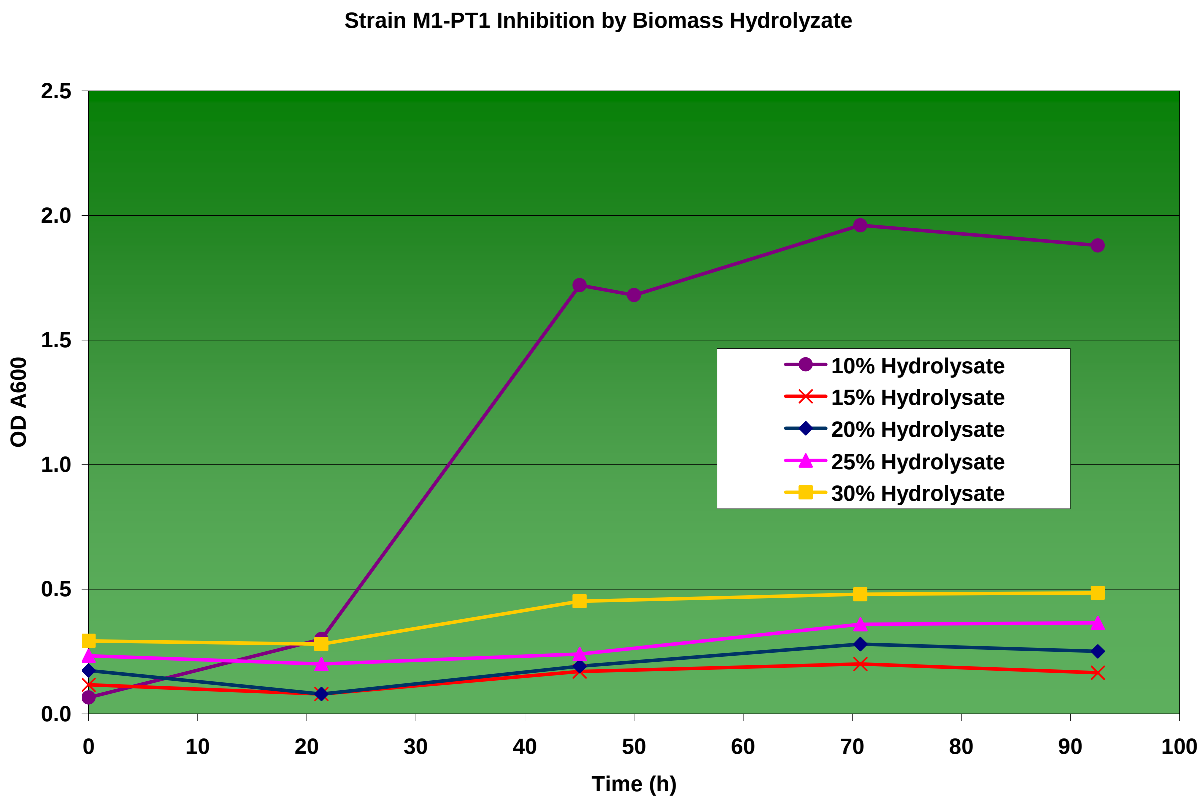


Figure 7.11 Hydrolysate inhibition

Strain M1-PT1 was serially transferred through a series of complex media shake flasks with greater levels of hydrolyzate to increase tolerance. The hydrolyzate level was increased 1-4% per transfer and 2-3 transfers were performed per week. Initial growth required as long as 96 hours.

Tolerance was increased from a starting level of 10% to 40% hydrolyzate over a period of two months. While growth was achieved at 40% hydrolyzate, the biomass produced was limited and the fermentation rate significantly slower than the no hydrolyzate control.

Conclusions:

Significant progress was made in optimization of batch fermentation parameters for improved production of ethanol or lactic acid from biomass sugars.
Adaptation studies showed the potential to increase xylose utilization and hydrolysate tolerance in biocatalysts. These learnings will be applied to the next generation of improved biocatalysts as progress is made toward commercialization. No insurmountable barriers were found with respect to ultimate scale-up of the technology.

Task 8.1 *Producer/Converter Business Relationship Analysis* (ISU/Wallace) -

The objective of this task was develop a model of possible business relationships between producers and converters in industrial biobased products supply chains. A team, The Bioeconomy Working Group (BWG), was assembled with representatives from a range of agricultural stakeholders including farmers/producers, small business, large business, Government and University. The work was coordinated by Jill Euken at Iowa State University Extension.

The Bioeconomy Working Group (BWG) met approximately 3 times per year during the course of the project. The 1-2 day meetings included updates on project actions and outside speakers on a variety of topics relevant to the team mission. For example, in November of 2003. The group began the process of exploring optional models for (1) producer supply groups, and (2) producer/ converter relationships Sissel Waage of The Natural Step gave a presentation to the group and facilitated discussion. The Natural Step is a nonprofit educational organization working to build an ecologically and economically sustainable society. The Natural Step offers a framework that centers on scientifically based principles for sustainability. The framework encourage consensus-based dialogue as a means of addressing complex environmental and social issues, and it recognizes that what happens in one part of the system affects every other part, often in unexpected ways. Sissel Waage and Eric Olson of The Natural Step further worked with the group in April of 2004.

The broad-based stakeholder team met in retreat session July 14-15, 2004. The group continued to explore potential models for (1) producer supply groups, and (2) producer/ converter relationships. The July meeting included presentations by:

- Brendan O'Connell, CEO of a hops producer group (Washington state) to learn about their unique organizational structure and their formula pricing system with their customers.

- Joe Nalley, Senior Vice-President of OSI (exclusive meat supplier to McDonalds); to discuss OSI's sustained supplier relationship with McDonalds for over 50 years.

- Kent Vickre, Iowa Farm Business Association; to learn about the methodology for farmers to develop a system to quantify real costs of production.

The group also developed a sustainability matrix which outlines the characteristics of supply chains for biobased businesses which are economically, environmentally, and socially sustainable

Deliverable 1 (optional models for producer supply groups and optional models for producer/converter relationships) was completed on schedule at the end of October 2004(Project Milestone 2). The report was uploaded to the DOE site as part of the project report and is attached as an appendix to this final report. ISU/Wallace plans to present and/or publish these results in the near future. The Bioeconomy Working Group met again on November 16, 2004 to refocus efforts on establishing actual supply chain relationships.

The BWG met on February 9th, 2005. The speaker for the meeting was Peter Goldsmith. Goldsmith is an agricultural economist who has specialized in the analysis of agricultural producer value-added ventures. Goldsmith suggested that agricultural producers should be very wary of making decisions to vertically integrate by making huge investments into processing. Rather, he suggested, producers should "work backwards" from a specific need identified by a customer, and then figure out how to produce the product ACCORDING TO THOSE SPECIFICATIONS.

The Bioeconomy Working Group met on June 22, 2005. The meeting included a tour of test plots at Iowa State containing crops of seed flax, Kenaf, and switchgrass. These crops are being tested as alternate crops with the potential use as feedstocks for energy and/or industrial products. The meeting focused on a review of progress to date and discussion of priorities moving forward.

Summary for Decision Point B:

It was not yet possible to specify a detailed business model between producer groups and NatureWorks LLC (formerly Cargill Dow LLC), as there are still large uncertainties in stover storage options, process parameters, planned product mix, and commitment towards construction of a full-size plant. However, there are a number of factors which limit the likely relationship to a few choices.

Factors:

- There is currently no commodity market for corn stover.
- A commercially viable plant will require a steady (large) supply of stover of some minimum quality (yet to be defined), which may require the harvest of a significant percentage of stover in the area surrounding the plant.
- The plant represents a large capital investment for the processor, so investors will want limits on risks. Thus the producer will want to initially control the technology from stover to products and have some boundaries on raw material costs.
- It is unlikely that stover can economically be delivered to a plant from distances more than 50 miles from the plant site. This will dictate mutually beneficial relationships between the processor and the producers in the area of the plant.
- There will be a need for producers to invest in additional equipment for harvest and/or transport of stover.
- Producers will not be inclined to invest in new harvest equipment, storage systems, and additional fertilizer without assurances of a price that will cover their costs plus provide a reasonable profit.
- State or local entities (private or government) may need to invest in storage and/or transportation infrastructure to enable success.

Therefore, it is likely that the relationship would involve a multiyear supply contract (processor with purchase guarantees, producer group with supply guarantees). Price will likely be fixed or calculated based on some formula (possibly a cost plus). Initial quality requirements will be specified (and subject to refinement based on improvements in harvest/process technology and knowledge, as well as improvements in processing efficiencies). The relationship may fit in the category of "quasi-vertical integration" with producers investing in harvest/storage/transportation equipment and the processor building and operating the plant under a long term contract between the parties. The initial contract may also involve commitments from state/local government or other entities (e.g. barge or railroad companies) to facilitate success of the venture. Note that the upper limit on stover value will be defined by the economics of the biorefinery. Construction of the biorefinery does not make sense if all parties involved are not able to realize reasonable profits. The relationship between producers and processor will need to be refined over time so that the system continues to meet the triple bottom line for sustainability.

Specific benchmarks (stover composition, average yield per acre, recommended cut height, etc.) were anticipated for the final summary of task 8.2. However, this task was terminated due to elimination of project funding in FY2006.

As a follow-up from the June meeting, the Bioeconomy working decided to conduct a study of several different ownership models for ethanol plants in Iowa, and how and to whom benefits accrue for different types of business arrangements. Task leader Jill Euken subsequently met with researchers in the ISU Economics department and made arrangements for them to conduct the study. Approximately $18,000 from project partner, Kellogg Foundation, was used to fund the work. This is part of the effort to develop and promote appropriate business models for ultimate construction and operation of a biorefinery.

This task was terminated early due to elimination of project funding in FY2006.

Conclusions:
The upper limit on stover value will be defined by the economics of the biorefinery. Construction of the biorefinery does not make sense if all parties involved are not able to realize reasonable profits.It is likely that the initial relationship would involve a multiyear supply contract (processor with purchase guarantees, producer group with supply guarantees). Price will likely be fixed or calculated based on some formula (possibly a cost plus). Initial quality requirements will be specified (and subject to refinement based on improvements in harvest/process technology and knowledge, as well as improvements in processing efficiencies). The relationship may fit in the category of "quasi-vertical integration" with producers investing in harvest/storage/transportation equipment and the processor building and operating the plant under a long term contract between the parties. The initial contract may also involve commitments from state/local government or other entities (e.g. barge or railroad companies) to facilitate success of the venture.

Task 8.2 *Producer/Converter Business Relationship Support* (IronHorse Farms)

See Task 1.2 summary.

Table of Milestones and Decision Points.

MS/DP	Description	Task	Planned Completion	Actual completion	Comments
MS 1	Best hydrolysate fermenting biocatalyst strain(s) identified for year 3 & 4 development.	7	9/30/2004	9/28/2004	Biocatalyst C1 selected at prime candidate for further development.
MS 2	Convene broad-based stakeholder team; publish study that outlines and analyzes optional models for: (1) producer supply groups, and (2) producer/converter relationships	8.1	10/31/2004	10/02/2004	
MS 3	Storage Bunker complete and ready to receive new crop stover	2.1	11/30/2004	9/28/2004	

DP A	Decision point: Determine need for "Slurry store" (by March 2005)	2.1	3/31/2005	3/31/2005	Based on water runoff permit restrictions, and if preferred moisture level of processing & storage is >72%.
DP B	Select model for relationship between Cargill Dow LLC and producer groups; outline and analyze options for integrated business model for biorefining that incorporates sustainability principles; characterize benchmarks for early adoption of biomass feedstock supply activities by producers; characterize benchmarks for early utilization of biomass feedstocks by converters	8.1	5/31/2005	5/31/3005	See details of relationship model reported under task 8.1. Benchmarks were be summarized in final report of task 8.2., but this task never completed due to early termination of DOE funding.
MS 4	All tests completed and final report issued: Effects of stover storage on corn fiber quality.	3	5/31/2006		Most samples analyzed, but completion of MS prevented by termination of project funds.
MS 5	Validation system & procedures for year 4 are defined	7	5/31/2006		Milestone abandoned due to termination of funding effective FY 2006.
MS 6	Design & testing of final version(s) of harvest and/or compaction equipment	1.1	1/31/2007		Milestone abandoned due to termination of funding effective FY 2006.
MS 7	Completion of final project deliverables.	all	5/31/2007		Milestone abandoned due to termination of funding effective FY 2006.

Patents: [A cumulative list of patents applied for or resulting from the award]
No patent applications were submitted under this project

As previously reported, IronHorse Farms Inc. has submitted an Invention disclosure to the DOE Chicago Operations Office and has been assigned a case number (S-104,734). The invention covers aspects of inorganic accumulation within the corn plant and what these accumulations might mean to any link in the value chain.

Publications / Presentations: [Identify and attach all publications and presentations made for industry or government groups resulting from the award during this quarter.]

Presentations

"Assessing the value of a targeted corn stover harvest by understanding the distribution of inorganic nutrients"
Poster presentation at "27th Symposium on Biotechnology for Fuels and Chemicals" held in Denver, CO. in May 2005.
Tom Schechinger[1] and Steve Thomas[2]
[1] IronHorse Farms, Inc., Harlan, IA 51537
[2] National Bioenergy Center, National Renewable Energy Laboratory, Golden, CO 80401

"Quality Changes During Bunker-Ensiled Storage of Corn Stover for the Biorefining Industry"
Poster at the 28th Symposium on Biotechnology for Fuels and Chemicals, Nashville, Tennessee April 30 to May 3, 2006.
Corey W. Radtke, Christopher T. Wright, Kevin L. Kenney, Peter A. Pryfogle, Reed L. Hoskinson, Heather G. Silverman, D. Brad Blackwelder, Neal A. Yancey, Debby F. Bruhn, Cindy R. Breckenridge, and J. Richard Hess (Idaho National Laboratory, Idaho Falls, ID 83415-2203)
Earic Bonner, William E. Bond, LaKenya T. McNear (Livingstone College, Salisbury, NC 28144)
Tom M. Schechinger (Iron Horse Farms, Harlan, IA 51537)

Publications:

White paper: "Supply Chain Options for Biobased Businesses" Lummus, R., Fall 2004 67 pages; available through The Leopold Center for Sustainable Agriculture, Iowa State University, 2003.; attached in appendix.

Appendix:

Supply Chain Options for Biobased Businesses" Lummus, R., Fall 2004

A final report prepared for the Leopold Center for Sustainable Agriculture

09/27/04

Supply Chain Options for Biobased Businesses

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Project time frame: 2 years.
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Table of Contents

Nontechnical Summary

The purpose of this paper is to investigate supply chain business relationships that would be most appropriate for biobased businesses. A framework is required that identifies the business structures available to farmers producing products to serve the new bioindustries *which translate into wealth creation for farmers*. The manner in which biobased businesses are developed will have tremendous implications for the future wealth of Iowa's farmers, communities and the economic condition of the state. While there may be great opportunities for large scale farms using best practice management standards to succeed in the new bioeconomy, it is more difficult to envision the role of the mid-sized farmer. How should these farmers look to improve their profitability as they begin providing products to biobased processing companies?

An initial literature review provided background on supply chain practices and identified best practices in supply chain management. A discussion of existing agricultural business supply chain practices was included. Finally, a complete discussion of possible business structures was developed along with an analysis of benefits and disadvantages for all links in the supply chain. While none of the models provides the perfect solution for farmers, the benefits of strategic alliances that are long term and based on trust between partners appear to have the most potential for new biobased businesses.

With strategic alliances both parties share the risks and benefits and both make decisions. These relationships are often flexible and trust-based and both parties work towards a mutual goal. Both groups use their complementary assets to gain long-term competitive advantage for the supply chain. The relationships often are very broad and difficult to define by contract and generally need to be built over time. Strategic alliances also allow for product differentiation, improved traceability and quality specifications. Since these relationships are trust-based both the

farmer and the processor must be committed to making them work. There is generally no penalty for one or the other defecting from the agreement. The relationships generally require systems for sharing information; and some of the detailed information required, such as product or processing costs, may be difficult for either side to disclose. Also, there must be a group of committed growers to make an alliance feasible, and then they are likely to give up some independence.

Supply Chain Options for Biobased Businesses

Abstract

The purpose of this report is to investigate and evaluate existing supply chain structures currently being used in biobased businesses, and corollary examples of supply chains in businesses of all types (U.S. and abroad). In addition it will identify key characteristics of each structure, and analyze the benefits and disadvantages for each type of structure.

Introduction

Economic development and growth in the 20th Century was driven by the industrialization of crude oil, coal, and natural gas as raw materials for chemicals, fuels, materials, and energy. Sustainable economic development for the 21st Century dictates that biorenewable resources provide a new foundation for these sectors of the economy. The rise of biorenewables, like the rise of oil a century ago, will offer rich rewards for those with the knowledge, creativity and technical innovation needed to turn vision into reality.

The U.S. Department of Agriculture (USDA, 2004) defines biorenewable resources, or biomass, as any organic matter that is available on a renewable or recurring basis, excluding old-growth timber and including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, wood and wood residues, animal wastes, and other waste materials. Waste materials include biological wastes, predominantly from corn, and can include paper mill, wood, and municipal solid wastes. They further define the term "biobased product" as any commercial or industrial product (other than food or feed) that utilizes biological products or renewable domestic agricultural (plant, animal, or marine) or forestry materials. Examples of bioproducts derived from animals include: adhesives, personal care products, nutraceuticals and pharmaceuticals from cattle and swine as well as heat, light, electricity, fuels, and fertilizer from animal waste. Examples of bioproducts derived from plants include: ethanol, plastics, cleaning solvents, and road de-icer from corn; packaging films, paper whitener, and water repellent coating from wheat; dyes, specialty chemicals, and lubricants from kenaf; and coatings, adhesives and biodiesel from soybeans.

Examples of firms and the products they produce can be found in The Journal of Industrial Ecology (2004). They describe four examples of biobased companies. 1. California Agriboard, LLC (CalAg) a private California corporation which will begin producing a new medium-density fiberboard in Willows, California in 2005. CalAg will utilize rice straw as the feedstock for producing the fiberboard. 2. In 2002 Cargill Dow LLC, based in Minnesota, began large-scale production of a proprietary polylactide polymer, NatureWorks PLA, from field corn. The facility, which represents nearly $750 million in investments, is capable of producing more than 300 million pounds (about 136 million kilograms) of NatureWorks PLA per year and using up to 40,000 bushels (about 1.4 million liters) of corn per day. The resin is being shipped around the globe for use in producing food and nonfood packaging, disposable cups and utensils, comforters, pillows, carpet tiles, and apparel. 3. KP Products Inc., known as Vision Paper, in 1991 became the first company in the world to produce paper made from 100 percent kenaf and processed without the use of chlorine bleaching chemicals. The company produces high-quality paper at a competitive price. 4. GEMTEK_ Products, first established in 1991, manufactures a broad range of biobased chemicals including cleaners, solvents, lubricants, personal care products, specialty products such as anti-allergen solutions, and alternative fuels. All of its products are produced from seed oils, related alcohols, and other materials from soy, corn, canola, peanut, palm, linseed, cottonseed, sunflower, jojoba, and others.

Another example of a company investing in biobased products is Herman Miller, a $1.34 billion office furniture company, which has incorporated several biobased items into a new line of products (Herman Miller, 2004). Kira is a proprietary panel system fabric made from 100 percent annually renewable biobased fiber derived from the plant sugars of corn. Kira contains no petroleum, yet it functions in the same applications as polyester synthetic fibers. It is suitable for a variety of textile products and applications, and can be completely composted at the end of its useful life. Wheat Board Core is a low-emission, rapidly renewable material composed primarily of wheat straw fibers. Herman Miller offers it as a standard option horizontal work surface on panel-based systems. Developed by Dow BioProducts Ltd., of Canada, Wheat Board Core is similar in appearance to particleboard and medium-density fiberboard, but it is made using a high-performance formaldehyde-free polyurethane resin. In addition to its rapidly renewable and low-emission qualities, Wheat Board Core is moisture-resistant and comparable in weight to standard particleboard.

Genencor (2004) is a diversified biotechnology company with over $380 million in 2003 revenues. In 2000, Genencor began working on a process to develop low-cost celluloses and other enzymes for the production of ethanol from biomass rather than from corn kernels. Genencor is working on a system to break down cellulosic material (plant matter) and other complex carbohydrates into fermentable sugars. These sugars are the raw materials refined into ethanol, organic chemicals and other bioproducts like plastics.

Other companies are investigating new biobased products (see U.S. Department of Energy, 2003). Dow Chemical has joined with Universal Textile, a carpet backing supplier, to launch the BIOBALANCE™ polymers line, a soy-based product that can replace a portion of the polyurethane carpet backing that is now the standard in carpet manufacture. This product also can be used in automotive interiors and other textile applications. Procter & Gamble, a major producer of household products, has formed a “technology council” with Archer Daniels Midland (ADM) to develop new natural products that take advantage of P&G marketing strengths and ADMs biobased raw materials. P&G also is working with the USDA to develop a process for producing lauric oil from cuphea, an oilseed that grows in the U.S., rather than from expensive imported tropical oils.

To foster the development of biobased businesses, it has been suggested that developing a system of biorefineries (multiple, synergistic bioprocessing businesses) could be the foundation for the new businesses. At the same time, these biorefineries would create significant opportunities for agriculture. The biorefinery is similar in concept to the petroleum refinery, except that it is based on conversion of biomass feedstocks rather than crude oil. Biorefineries would use multiple forms of biomass to produce a flexible mix of products, including fuels, power, heat, chemicals and materials. Additional information on biobased businesses and products can be found at the Biobased Manufacturers Association (2004) web site.

SustainableBusiness.com (2004) describes activities the federal government has engaged in to support early market growth in demand for bioenergy and biobased products. Congress enacted the Biomass Research and Development Act of 2000, to bring new focus to public sector involvement in the conversion of biomass into biobased industrial products, including bioenergy. The legislation called for increased coordination across federal government departments and agencies associated with biomass research and development (R&D); and the USDA and the Department of Energy (DOE) were designated as the lead departments in that effort. The 2002 farm bill created a program for preferred procurement of biobased products (not including motor fuels and electricity) under which federal agencies must buy biobased products. The federal government also supports ethanol demand by providing a reduction in federal gas tax for each gallon of gasoline with a 10 percent ethanol blend.

While there is much interest and support for biobased businesses, the development of these businesses requires advances in science and technology, evaluation of agricultural practices and resolution of supply chain issues. The issue of ***supply chain development*** for biorefineries is discussed in both the national and Iowa vision and roadmap documents for biobased products and bioenergy. The national vision and roadmap document highlights the need for research and development for *"addressing the facilities, location, handling and delivery issues for a plant-based feedstock supply chain, including mechanisms to **enhance the economy** of rural regions"* (see U.S. Department of Energy, 1998). The newly released Iowa vision and roadmap (Iowa State University Extension, 2002) likewise lists two specific needs related to supply chain development:

1. Research and demonstration programs to assist (model) new business arrangements *between* agricultural producers (coops and alliances) that provide necessary quantities for biomass for biorefineries;
2. Research and demonstration of creative business relationships *between links* of biobased supply chains.

Clearly, the ***manner*** in which the biorefineries are developed will have tremendous implications for the future wealth of Iowa's farmers and communities and for the economic condition of the state. While there may be great opportunities for large-scale farms using best practice management standards to succeed in the new bioeconomy, it is more difficult to envision the role of the mid-sized farmer. Should these farmers plan to get ahead by moving up the value-added ladder and gaining some of the profits from further processing their raw materials into semi-finished products? Many in the industry believe this is the model to follow. In the last few years, a number of farmer-owned manufacturing facilities have been established, particularly in the bioenergy area.

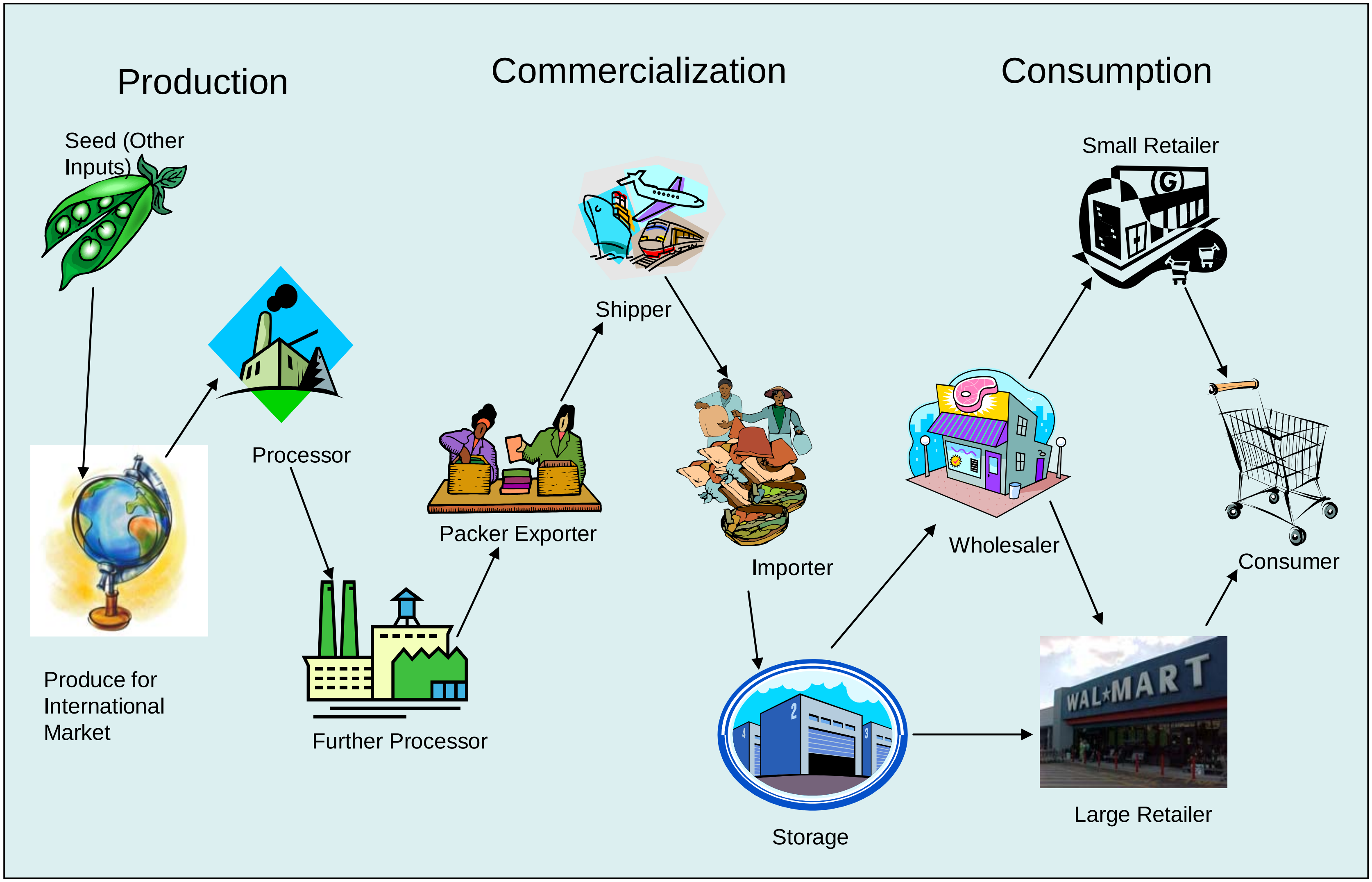
Another view that has gained favor is that of developing "biocenters" close to the source of biomass supply (in rural areas). The biocenters will process particular inputs into semi-finished products which then move to another nearby location for further processing. These biocenters would result in jobs, income, and an improved tax based for rural communities. While most would agree that these new businesses would be an asset to the state of Iowa, no one is quite sure of the impact on farmer income and wealth creation. As Morris notes (2000), other agricultural products, such as corn, have seen increased productivity without corresponding increased revenue to farmers. Concentration in the retail and food processing industries has driven requirements for lower costs. Morris suggests that in the new bioeconomy, it is imperative that farmers be rewarded for their output.

A framework is required that identifies the business structures available to farmers who are producing products to serve the new bioindustries *which translate into wealth creation for farmers*. This paper is designed to identify those structures. The paper will begin with an initial literature search which describes potential benefits from biobased businesses. Next, it will provide background on the development of supply chain practices and identify best practices in supply chain management and in buyer/seller relationships. Third, it will investigate non-biobased agricultural business supply chain practices and discuss their current use. Finally, a complete discussion of each business structure will be provided to evaluate the effectiveness for farmers. The discussion will include:

- description of specific business model,
- description of supply chain partners,
- analysis of benefits (for all links for the supply chain and for the community where the business resides), and
- analysis of disadvantages (for all links of the supply chain and for the community).

The need to study business structures and relationships within agriculture has been recognized for some time. Rausser et al. (1987) noted that studies of contractual arrangements and organizational structures are needed in food marketing systems. They believed future research should focus on relationships between contract organizational forms, agricultural policy programs and social institutions. Figure 1 describes a typical international agriculture supply chain.

Figure 1: Typical Agricultural Supply Chain



Estimates of Potential Farm Level Benefits from Biobased Clusters

The importance of biobased business has been emphasized earlier by government entities encouraging a move from a petroleum-based society. The potential overall market size of biobased business is difficult to identity. A study by Agriculture and Agri-Food Canada (Crawford, 2001) of biobased markets estimated the potential market size by 2005 for five clusters of businesses (see Table 1). The estimates were based on studies of U.S. market trends and interviews with industry and government representatives in Canada. Among the more interesting data were their estimates of the calculated net benefit to farmers, using the average raw material prices typically paid by industries operating within each market cluster. The total projected sales in 2005 were $2.68 billion. The total net value to farmers was projected to be $421 million per year by 2005 or about 16 percent. The study indicates biobased businesses will have a significant impact on the economy and can provide an increase in revenue for farmers. A major challenged noted in the report was the commercialization of innovations within biobased products.

An interesting supply chain consideration as the economy shifts from petroleum-based to biobased is that the location of processors and the jobs to support them in the supply chain will shift (Armstrong, 2003). The economics of biobased materials will not support transporting them much farther than 250 to 300 miles from their growing location. Biorefineries will have to be built close to where the product is grown. Regionalized agriculture is likely to result, with certain products being grown close to processors. This likely will create non-farming jobs in rural areas.

Table 1: Estimates of Potential Farm Level Benefits from Industrial Use Clusters - 2005

Industrial Market Cluster	**Industries**	**Potential Market Size ($millions)**	**Farmer Benefit (%)**	**Farmer Value ($millions)**
Biochemical	- resins, plastics, paints, coatings, soaps, cleaning compounds, toiletries, fragrances, cosmetics, lubricants, greases	1690	10	170
Biomass fibres	- fibre products like strawboards	570	35	200
Health	- nutraceuticals, essential oils, pharmaceuticals, drugs and medicines	260	8	21
Energy	- ethanol, biodiesel, electricity, fuel additives, lubricants and greases	110	15	17
Environment	- bioremediation, phytoremediation, biocontrols	50	25	12.5
Total		**2680**	**16%**	**421**

Source: Crawford, C. (2001) Developing Biobased Industries in Canada, Canadian New Uses Council (CANUC), http://www.agr.gc.ca/misb/spcrops/sc-s_e.php?&page=framework#2.3

Background on Supply Chain Management

Supply chain management is a concept that has emerged since the early 1990s as companies realized they could no longer compete independently, but required the cooperation of their supplier and customer partners. Porter's work on value chains and value systems captures the essence of organizing activities within and between firms in order to transmit value to the ultimate customer (Porter, 1985). Ellram and Cooper (1993) defined supply chain management as "an integrating philosophy to manage the total flow of a distribution channel from supplier to ultimate customer." Monczka and Morgan (1997) state that "integrated supply chain management is about going from the external customer and then managing all the processes that are needed to provide the customer with value in a horizontal way." They believe that supply chains, not firms, compete and the strongest competitors are those that "can provide management and leadership to the fully integrated supply chain including external customer as well as prime suppliers, their suppliers, and their suppliers' suppliers." A key point in supply chain management is that the entire process must be viewed as one system. Any inefficiencies incurred across the supply chain (which includes suppliers, manufacturing plants, warehouses, customers, etc.) must be assessed to determine the true capabilities of the process.

Why has managing the supply chain become an issue? In part, this is because few companies continue to be vertically integrated. Companies have become more specialized and search for suppliers who can provide low-cost, quality materials rather than cultivate their own source of supply. It becomes critical for companies to manage the entire supply network to optimize overall performance. These organizations have realized that whenever a company deals with another company that performs the next phase of the supply chain, both stand to benefit from the other's success.

A second reason partially stems from increased national and international competition. Customers have multiple sources from which to choose to satisfy demand; locating product throughout the distribution channel for maximum customer accessibility at a minimum cost becomes crucial. Previously, companies looked at solving the distribution problem by maintaining inventory at various locations throughout the chain. However, the dynamic nature of the marketplace makes holding inventory a risky and potentially unprofitable business practice. Customers' buying habits are constantly changing, and competitors are continually adding and deleting products. Changes indemand make it highly likely that the company will have the wrong inventory. The cost of holding any inventory also means most companies cannot provide a low-cost product when funds are tied up in inventory.

A third reason for the shift in emphasis to the supply chain is because most companies realize that maximizing performance of one department or function may lead to less than optimal performance for the whole company. Purchasing may negotiate to lower the price on a component and receive a favorable purchase price variance, but the cost to produce the finished product may rise due to inefficiencies in the plant. Companies must look across the entire supply chain to gauge the impact of decisions in any one area.

Advanced Manufacturing Research, a Boston-based consulting firm, developed a supply-chain model which emphasizes material and information flow between manufacturers and their trading partners (Davis, 1995). They believe the changes required by management are due to the following changes in how manufacturers are doing business:

- Greater sharing of information between vendors and customers,
- Horizontal business processes replacing vertical departmental functions,
- Shift from mass production to customized products,
- Increased reliance on purchased materials and outside processing with a simultaneous reduction in the number of suppliers,
- Greater emphasis on organizational and process flexibility,
- Necessity to coordinate processes across many sites,

- Employee empowerment and the need for ‘rules-based’ real time decision support systems, and
- Competitive pressure to introduce new products more quickly.

Companies are streamlining all operations and minimizing the time-to-customer for their products.

The history of supply chain management began with work in both the textile and grocery industry supply chains. Due to intense competition in the textile and apparel industry world-wide, leaders in the U.S. apparel industry formed the Crafted With Pride in the U.S.A. Council in 1984 (Kurt Salmon Associates, Inc, 1993). In 1985, Kurt Salmon and Associates were commissioned to conduct a supply chain analysis. The results of the study showed the delivery time for the apparel supply chain, from raw material to consumer, was 66 weeks long, 40 weeks of which were spent in warehouses or in transit. The long supply chain resulted in major losses to the industry due to financing the inventory and the failure to have the right product in the right place at the right time.

The result of this study was the development of the Quick Response (QR) strategy. QR is a partnership where retailers and suppliers work together to respond more quickly to consumer needs by sharing information. Significant changes as a result of the study were the industry adoption of the UPC code used by the grocery industry and a set of standards for electronic data interchange (EDI) between companies. Retailers began installing Point of Sale (POS) scanning systems to transfer sales information rapidly to distributors and manufacturers. Quick Response incorporates marketing information on promotion, discounts, and forecasts into the manufacturing and distribution plan.

In 1992, a group of grocery industry leaders created a joint industry task force called the Efficient Consumer Response (ECR) Working Group. The group was charged with examining the grocery supply chain to identify opportunities to make the supply chain more competitive (Kurt Salmon Associates, Inc, 1993). Kurt Salmon Associates were engaged by the group to examine the grocery supplier/distributor/ consumer value-chain and determine what improvements in cost and service could be accomplished through changes in technology and business practices.

The results of the study indicated little change in technology was required to improve performance. However, the study identified a set of Best Practices which, if implemented, could substantially improve overall performance of the supply chain. As Kurt Salmon and Associates (1993) found, "By expediting the quick and accurate flow of information up the supply chain, ECR enables distributors and suppliers to anticipate future demand far more accurately than the current system allows." Through implementation of Best Practices they projected an overall reduction in supply chain inventory of 37 percent, and overall cost reductions in the industry in the range of $24 to $30 billion.

Best Practices in Supply Chain Management

A discussion of biobased business supply chains should include a review of best practices in current supply chains. In their article on "New Business Models for Supply Chain Excellence," Mulani and Lee (2002) describe many of the issues facing supply chains today and provide examples of well-run supply chains. Dell Computer is often cited as one of the more successful supply chain examples. Dell uses a consumer-direct approach based on build-to-order manufacturing, effective supplier management to shorten component lead times, eliminating inventory through just-in-time processes, and using technology to integrate tightly with customers and suppliers. Cornerstones of Dell's strategy are: sell what you have and use day-to-day pricing and incentives to shift demand; minimize stock - their average inventory is less than four days; ensure quick product life cycle transitions; leverage immediate customer feedback and market insights; and control pricing every day. Dell has linked its supply chain directly to corporate customer processes and operations via custom-tailored account pages for each customer and various other customer services. This allows Dell to build knowledge of the customer, be more sensitive to changes in customer processes and technology, and solidify barriers to entry by competitors.

Scholastic, the world's leading publisher and distributor of children's books, is a good example of a company that uses the right channel strategy to create barriers to entry for supply chain competitors (Mulani and Lee, 2002). Its direct-to-classroom book club business treats each teacher as an individual customer; coordinates several offers and products simultaneously; accommodates tight order-fulfillment time frames along with periodic spikes in demand and multiple SKUs; and enhances school-channel loyalty with syllabus support materials, credits for free books, and classroom technology support. Scholastic uses their supply chain channel strategy to improve its competitiveness.

Other company examples of specific areas of supply chain success are provided by Hildebrand (1998). Bergen Brunswig Corporation, a pharmaceutical and medical supply distributor, signs performance-based contracts with customers and shares supply chain cost reductions over 10 percent with their customers. McKesson Corporation, a pharmaceuticals and medical supplies distributor, provides skills and funding for supply chain partners to gain the right technology. After implementation, both McKesson and the partner take advantage of cost savings. Their philosophy is "a partner that has been helped rather than left on its own is one that may eventually return the favor." Dana Corporation, an automotive parts manufacturer of chassis for Ford, Chrysler and others, extends the supply chain into product design. They provide input on how to save money on parts while their customers' vehicles are still on paper and ask their suppliers for the same input. Home Depot, a retailer of home improvement products with 1278 stores in the United States, helps suppliers get manufacturing loans. Home Depot realizes that if banks know that Home Depot is behind a company and wants to buy their product, it will likely help get the investment. At the same time, Home Depot wins a loyal supplier. What all of these companies recognize is that their supply chain is only as strong as its weakest link and they work with their partners to improve performance.

A general summary of supply chain "best practices for successful supply chains" would include:

- Reducing the number of suppliers,
- Emphasizing total acquisition cost,
- Focusing on relationship management,
- Practicing global sourcing, and
- Making product decisions based on purchase price, lead-time, technology, flexibility to respond to change, economic and political stability.

A focus on relationship management includes regularly sharing information on plans, customer needs, capacity, and supply chain costs. Partners are selected on the basis of mutual interest and values. A portfolio of partnering strategies is used where a one-time small dollar value purchase would not suggest that a partnership would be appropriate. Traditional, open-market, negotiated interactions may make the most sense with commodity-type products. Practicing global sourcing includes looking at the best source of product to supply global operations and requires managing a complex array of networks and alliances. With global purchasing, landed cost and access to high-quality materials and technology are the factors that drive purchases.

Many of the improvements in supply chain performance would not have been possible without similar improvements in the technology information systems that are the backbone of most well-run supply chains. Companies today use the World Wide Web and the Internet to exchange information between supply chain partners and with end customers. The wide-spread usage of Enterprise Resource Planning (ERP) systems has allowed companies to track inventory and scheduling plans internally and then share that information with supply chain partners. In addition, new technology innovations are changing the way supply chains perform. For example, e-auctions allow companies to list products for sale via the Internet and auction them to the highest bidder. Best candidates are commodity products (i.e., price-driven products), though companies are beginning to use e-auctioning for more strategic materials. Private exchanges electronically synchronize a firm's supply chain with those of its strategic trading partners to buy, sell, and move goods more efficiently. Product design collaboration using decision support systems manages design across the lifecycle of a product, from introduction to service support to obsolescence, by having suppliers become part of the design process. This helps cut design and production times, improves product quality, and achieves faster time-to-market.

The use of the Internet for direct sales to end customers has changed the structure of many supply chains, eliminating or supplementing middlemen such as wholesalers and retailers. Customers expect information about what is and is not in stock, ordering systems that are available 24 hours a day, and the ability to customize product requirements. Companies have been required to implement the on-line capabilities for customers to place orders but also have been forced to add new back office information systems to validate customer requested ship dates and make shipments to end customers in quantities as small as one item.

These best practices for supply chains are important benchmarks for new agricultural biobased businesses to consider. Many of the biobased supply chains will be competing with existing, highly efficient supply chains with years of process improvement history. To be successful, the new businesses must begin with many of these best practices as part of their supply chain structure.

Buyer-Seller Relationships

As part of understanding biobased business structures, it is important to understand the interactions between buyers and sellers. Relationships between buyers and sellers have long been studied in the purchasing, operations, and marketing literature. A good framework for the development of buyer-seller relationships as outlined in marketing theory can be found in Dwyer, Schurr and Oh (1987). Their summary describes two distinct types of transactions. Discrete transactions are those with little communication, short duration, and it matters little who fills the requirement. An example would be a spot purchase of unbranded gasoline out-of-town at an independent station. Relationship transactions result from increased dependence and possibly from legal obligations. Examples include long-term associations (loyalty programs such as frequent flier programs, book or record clubs, season tickets for sports), contractual relations, and other collaboration efforts. The authors describe the analogy of the interpersonal and interdependent relationship between husbands and wives as a good framework for describing the evolution of buyer-seller relations. They also discuss the importance of switching costs in situations. If the buyer incurs high switching costs, due to the technology or use of the product, they have a significant interest in maintaining a quality relationship. Costs of maintaining a relationship may be high for both partners and the relationship needs to be advantageous to both.

Further marketing research by Noordewier, John and Nevin (1990) describes the various characteristics that move a relationship from a discrete transaction to a genuine relationship. The necessity for the supplier to be *flexible* (in terms of adjustments to price, inventory, quick deliveries, product changes, etc.) moves it closer to a relationship rather than a discrete, one-time purchase of a given item of fixed design and price. Relationships increase as the supplier provides more *assistance* to the seller, i.e. with product design, advance shipment notice, or notification of product problems or delays. When buyers require significant *information* from the seller such as product specifications, delivery schedules, long-term forecasts, and planning schedules, the transaction moves from discrete to more relational. Situations where the buyer must *supervise or monitor the supplier's actions* to ensure specific behavior increase the relationship aspect of the transaction.   The last situation that affects the relationship is the *expectation of future exchange* between the two parties. The relationship grows as the parties expect to do business over a longer period of time and often without a termination date.

The operations literature describes the techniques used by the Japanese in the early 1980s to collaborate successfully with suppliers which led to gains in manufacturing competitiveness in a variety of industries. The Japanese developed a supplier association, known as Kyoryoku Kai to improve relationships with suppliers (Rich and Hines, 1997). A supplier association was defined as "a mutually benefiting group of a company's most important subcontractors, brought together on a regular basis for the purpose of coordination and cooperation as well as to assist all the members to benefit from the type of development associated with large Japanese assemblers: such as kaizen, just-in-time, kanban, U-cell production and the achievement of zero defects."   These associations that served to coordinate the entire subcontracting system were used as a forum to discuss corporate strategy, and also to share engineering and cost information. This strategy of developing collaborative relationships recognized the dependency of the organizations on the supplier network and focused on the socialization process rather than the formal contract between the organizations. The system of subcontracting and building long-term relationships with suppliers has been very successful in Japan. One of the backbones of these relationships is that cost reductions and quality improvements are made by the companies working together. Suppliers remain highly competitive, but under partnership arrangements cost reductions are achieved through cooperation. Bargaining is based not on price alone, but rather on a target price, while maintaining a reasonable level of profit for the supplier. These relationships focus on mutual benefit.

Some authors believe that this success is only due to the nature of Japanese business relationships. Rather, they contend that buyer-seller relationships are really driven by the power maintained by one or the other organization in the relationships (Cox, 2001). Rather than viewing business relationships from an integrated supply chain perspective, Cox notes that businesses inherently are looking for the best return and as a result will wield whatever power is possible over their suppliers to ensure low costs or keep their competitors at a disadvantage. He defines one of four positions in which the buyer may reside. When the buyer is dominant, he can leverage the supplier's quality or cost and ensure that the supplier receives only average returns. When the supplier is dominant, the buyer will be limited by both the price and availability of the supplier's offering. In the situation when neither has leverage over the other, the supplier must take the current prevailing price, which may or may not be an advantage for the buyer. When the two are interdependent, neither party can force the other to do anything; as a result the two parties must work together closely. The supplier receives good returns but must pass on some of the value to the buyer.

Cox argues that companies must understand where they are in the power structure and find ways to move to a more favorable position of power in the relationship. It is his perception that the dominant position would be more favorable than any other given the nature of the competitive business environment. There certainly is support for Cox's view on power in relationships and its effect on supply chain partners. As Stine notes (2003), the large grocery retailers led by Wal-Mart are driving down prices for the products purchased from their suppliers. The supplier companies such as General Mills or ConAgra that feel the price pressure will in turn apply pressure to farmers. Rather than raise prices, Wal-Mart expects suppliers to cut the cost of producing their products to increase profits.

More recent studies on relationships between buyers and sellers have focused on the attributes that are important in business-to-business relationships. Rhinehart, et al., (2004) identified seven basic relationship types based on the attributes of trust in the other party, interaction frequency, and the commitment to the relationship. These relationship types include: alliances, administered relationships, contractual relationships, non-strategic transactions, joint ventures, specialty contract relationships and partnerships. Non-strategic transactions are based on an arms-length approach and on the economic capability of each party. Administered relationships may include one-time or multiple transactions and the relationships are managed through a non-formal strategy (i.e., supplier development programs). Contractual relationships are used when more formal control of the business is required. A high volume of business may be conducted, yet neither party is willing to invest in the other's business. Specialty contracts are used for unique products or services where there may be few buyers or sellers.

Rhinehart et al. (2004) continues by defining a partnership classification which is less formal than contracts, and no written agreements or legal documents are created. As such, there are more uncertainties between the parties and this can result in differences of opinion on performance. Joint ventures usually are completed through some form of financial investment by both parties with the goal of achieving mutual benefits. Joint ventures actually may be the result of a lower level of trust where the firms use financial investment to ensure performance. The final type of relationship is an alliance which involves some form of investment to achieve joint benefits. Alliances differ from joint ventures in that there is a greater degree of trust in the relationship and yet some degree of perceived dependence on the other party.

The advantages to partnering with a supplier from the buyer's perspective include (Ellram, 1995): 1.) ease of managing a smaller supply base, 2.) less time searching for new suppliers, 3.) mutual dependence results in stability and greater loyalty, 4.) more stable prices, 5.) joint planning and information sharing based on mutual trust, and 6.) better quality. Rudzki (2004) notes that partnering is not an easy process. As a practitioner, his company formed a strategic partnership with a supplier which evolved over 12 months of discussions and negotiations. "We explored strategic, cultural and operational aspects. We thrashed out relative competencies, risk sharing, and shared investment. And, of course we wrestled over price and delivery" (Rudzki, 2004 p. 51). He notes that businesses can no longer afford not to partner, but at the same time they cannot afford to partner poorly.

A summary of the differences in relationships between traditional buyer-seller markets and supply chain partnerships can be found in Table 2 (Fearne and Duffy, 2003).

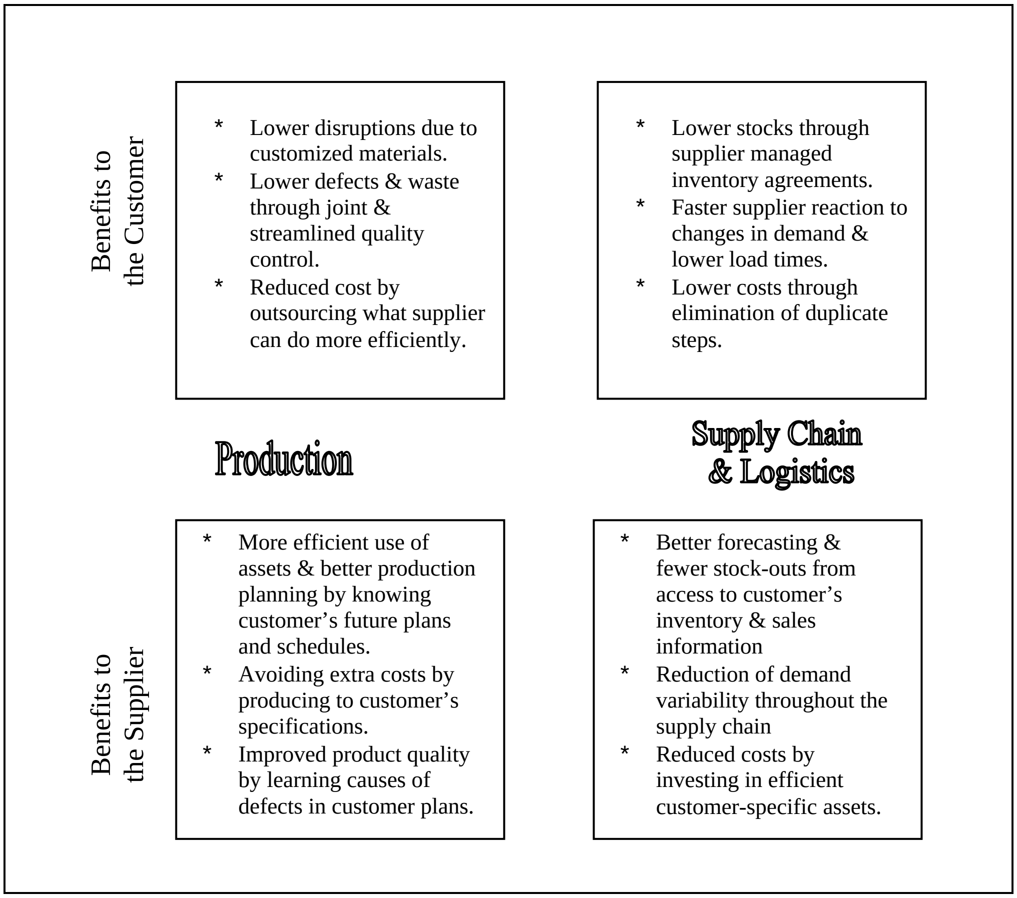
Table 2: Key extremes of buyer-supplier relationships

Traditional Arms-length Relationships	Supply Chain Partnerships
Short-term focus on individual transactions	Commitment to long-term relationships
Buying decision made on price	Buying decision made on value
Many suppliers	Fewer selected suppliers
Low interdependence	High interdependence
Haphazard production and supply scheduling	Order driven production and supply
Limited communication restricted between sales and purchasing	Open communication facilitated by multilevel/ multifunctional relationships
Little co-ordination of work processes	Integration / co-ordination of work processes
Relationship specific investments avoided	Increases in relationship specific investments
Information is proprietary	Information is shared
Clear delineation of business boundaries	Creation of inter-company teams
Use of threats to resolve disputes.	Joint problem solving approach to conflicts
Unilateral improvement initiatives	Continuous joint improvement sought
Separate activities	Engage in joint activities
Dictation of terms by more powerful firm	Joint decision making
Adversarial attitudes/combat	Cooperative attitudes/ teamwork
Conflicting goals	Compatible goals
Behave opportunistically	Mutual trust exists
Act only in own interest	Act for mutual benefit
Win-lose orientation	Win-win orientation

Source: Fearne, A. & Duffy, R. (2003) Partnerships in the Retail Food Chain, in Bourlakis, M. & Weightman, P (Eds), Food Supply Chain Management, Blackwell Publishing

Some potential benefits of supplier-customer alignment have been provided by Kashani (2004). He separates the benefits into those benefiting the customer and those benefiting the supplier. Figure 2 describes those benefits that result in the production and supply chain processes within the companies. Other processes, such as the new product development process, also would realize benefits from closer supplier-customer alignment. Achieving alignment with customers is not an easy process. Kashani (2004) describes the process IBM used in the 1990s to become connected with customers. Termed ‘Operation Bear Hug’, it forced the company’s top 50 executives to visit a minimum of five clients each within a year to find out what issues their customers were facing in order to align with their needs.

Figure 2: Supply Chain Benefits from Supplier/Customer Alignment



A succinct summary of the keys to successful development of partnership relationships, specifically in the food industry, is provided by Hughes and Ray (1994). These include:

1. Clear benefits for all partnership and alliance members.
2. Business proposition underpinning the partnership that makes long-term commercial sense.
3. Focus on specific partnerships, products and markets.
4. Build upon successful partnerships.
5. Apply lessons learnt from the partnership to gain benefits in other business areas.
6. Partners/alliance members should have a good strategic fit.
7. The commercial relationship should be based on interdependence.
8. Companies have similar corporate values and the same commercial ethos.
9. Mutual trust and respect.
10. Aim high on quality – make it difficult for others to follow.
11. For junior partners: pick a senior partner with a long-term commercial future
12. Build relationships and communication links among all levels of the two businesses.

13. Gain full endorsement of the venture by the most senior management and strong personal commitment of all staff.
14. Members should hold a common view on the long-term objectives of the partnership.
15. Partnership members should hold a common view of what the final consumer wants.
16. Raise the veil of secrecy and focus on sharing information required to make the partnership a success.
17. Investment in physical plant and, for horizontal partnerships, joint investment by members builds commitment to the venture.
18. Build flexible organizations that meet the specific needs of each partnership.
19. Fix problems as they arise – delays only serve to disrupt.
20. To ensure success, partnerships require their fair share of commercial good fortune.

Partners in these supply chains have a specific interest in seeing their partners succeed. They are not focused on a specific contractual relationship, but have built a relationship based on trust and mutual interdependence. New biobased businesses should consider these relationship issues as they begin working with supply chain partners.

Agriculture and Supply Chain Management

Supply chain management has been discussed in various agricultural industries and should be evaluated by new biobased businesses. In agriculture, the key stages in the supply chain include: basic science, crop production, processing, and product demand.   A good discussion of supply chain management and the food industry can be found in Hildred and Pinto (2002). They discuss the current concentration at the retail food level and in food manufacturing or processing. At the retail level in 1999, the four largest firms hold 43 percent of the market and the top six have more than 50 percent (including Kroger, Wal-Mart, Alberstons, Safeway, Royal Ahold and Del Haize).   This concentration also occurs among the large food manufacturing firms with the top six holding more than 50 percent of the market. In animal slaughter and processing the same concentration exists with four firms controlling from 42 to 79 percent of the market across the various commodities. There is every indication that this concentration is continuing across both retailers and food processors.

The same concentration might be said to be occurring in the farm sector where the number of farms continues to fall and more than 90 percent are considered to be small farms selling less than $250,000 per year (Hildred and Pinto, 2002). The largest 2 percent of the farms maintain over 50 percent of sales. However, the 2 percent is still made up of over 400,000 farms which indicates little true concentration. In some areas, such as with cattle production, more of the product is moving to be produced under contract with the processor, as already is the case in both poultry and hog production. As the authors note (p. 5), “Far from a consumer-friendly-competitive structure, the system for delivering food has nodes of significant market power at every stage.” The implications for these types of systems are that there may be anticompetitive behavior patterns across these supply chain connections.

McCluskey and O'Rourke (2000) discuss relationships between produce suppliers (fresh and frozen fruits and vegetables) and retailers noting the increased consolidation among retail grocers. Their study used an interview process to identify relationship issues between small to medium (sales of $10 to $50 million) fresh and frozen produce suppliers and large retailers in the western United States. The suppliers noted that business relationships are changing. Buyers are focused more on product specifications to pay for the quality received. They also noted downward pressure on prices as a result of power shifting to ever larger accounts. Personal relationships, once the norm with buyers, are falling by the wayside as consolidation increases. The suppliers expect the large retailers to reduce their number of suppliers and most expected some type of web-based information system for transactions be required in the future. They see a need for consolidation along the supply side, as large retailers will be more likely to select large suppliers.

Some retailers noted a preference to maintain a mix of small and medium-sized firms as suppliers although full truckload shipments to distribution centers were preferred (McCluskey and O'Rourke, 2000). Retailers only purchased from pre-qualified suppliers on approved vendor lists. All agreed that product quality and value were most important in choosing and retaining suppliers. Retailers also expect electronic transactions to play a bigger role in the future. Logistical efficiency was of prime importance to retailers and all were looking at improvements in distribution centers to improve response time. Delivery times were specified, with penalties for late delivery. Retailers encourage suppliers to work with them on joint efforts in advertising, promotion, merchandising, and food demonstrations. In summary, the authors recognize the shift in power to retailers and suggest the following recommendations to suppliers (p.19):

1. Better understand how food system demands are changing.
2. Push for standardization of electronic software across retailers.
3. Consolidate into larger units.
4. Form alliances with other producers, packers, and processors to achieve critical mass as cost-competitive suppliers.

They believe that requirements of the large retail chains will make it more difficult for small, under-capitalized firms to compete and survive.

In his discussion of supply chains in the European fresh produce market, Zuurbier (1999) evaluated how retail companies managed these supply chains. He also discussed the coordination devices, technology, and institutional arrangements they used. He identified a list of issues for the wholesalers, packers and shippers which made supply chain coordination particularly difficult (p. 23):

1. Perishability (loss of quality after harvest)
2. Guarantee of year-round supply (due to distances and lack of speed)
3. High logistics costs (the costs of physical distribution, packaging at the point of harvest, repackaging at the point of shipment, at the distribution center, and at the point of sale location)
4. High transaction costs (increased by the large number of suppliers, the assortment of produce, traditional administrative systems, and less than sophisticated buying offices)
5. The tendency to “add value” (along with the necessary investments)
6. The right of consumers and customers to know the place of origin, the production methods, the use of pesticides and insecticides, adding higher costs.

The key factors for successful coordination in rank order included: trust, duration of relationship between customer and supplier, consistent behavior, reliability, year-round supply, exchange of market information, openness and honesty, a relative power balance, and direct communication. Overall, the study uncovered the extreme importance of trust in relationships, where trust replaces monitoring and control. Trust underlies social ties and social contracts; and norms such as integrity, preserving relationships, and conflict handling enable the relationships.

Loader (1997) evaluated the true costs of conducting business, as a step toward improving systems and reducing costs. He used transaction economics to discuss relationships in the supply chain between Egyptian potato growers and consumers in the United Kingdom. His conclusions were that the importance of supply chain agreements increases when parties have highly dedicated assets, deal in large quantities, and when demand and supply is unpredictable. Dealing with a single negotiator reduces transaction costs, in particular when large volumes pass through the channels.

The potato grower example shows a marketing system with many small scale producers using a low level of technology on one end, and on the other end thousands of consumers all consuming small quantities of the product. In between are six to eight major export companies and their respective import companies, and a variety of retail grocery and restaurant outlets with a large portion of the product being sold through a small number of large supermarket chains. As a result, there is a huge contrast between the producers and consumers, and the intermediaries who handle the product. The intermediaries operate in an uncertain environment in terms of supply and market for their product, so there is a drive towards vertical integration. Exporters are trying to purchase directly from farmers rather than from cooperatives and increasingly are looking at contracting with farmers to ensure a supply source. The contracts often are informal and subject to cancellation at short notice. The exporters have the advantages of better education and access to market information and the farmer is generally disadvantaged in both areas. The retail grocery sector is continuing to concentrate with centralized buying which means suppliers may deal almost exclusively with a single negotiator, thus decreasing transaction costs and suggesting that closer relationships will form. Also, relatively large consignments pass through these channels, further reducing transaction costs.

An important issue for all supply chains, including those in agriculture, is information sharing across the supply chain. An example of sharing information can be seen in the case of Capespan, a South African distributor of fresh produce (IBM, 1999). The company distributes 83 million cartons of fruit (three-quarters of a million tons), to 66 countries on six continents on 250 voyages, from 3000 suppliers in South Africa. They have an information system which links growers, port inspectors, customs brokers, shippers, retailers and storage firms. As a result, all logistics and marketing data reach supply chain partners before the fruit arrives. A bar code system monitors all pallet movement and sales offices know what is available at any given time, which is very important given the perishable nature of the product. The flow of information allows Capespan to have the right product at the right place, not to worry about the logistics, and to focus on other business opportunities. Most growers are shareholders and are highly committed to the company's success. However, the information system begins when products are delivered to the packaging facility rather than at the farm.

These examples provide anecdotal information for new biobased businesses. Much can be learned from evaluating other agriculture supply chains. In particular, issues of logistics, power between supply chain partners, marketing channels, quality, and information technology must all be considered in new biobusinesses. The specific kind of relationship between partners will be important, but all of these business practices also must be developed.

Agriculture Relationships

General buyer-seller relationships are discussed in the business literature and will apply equally well to agricultural biobased grower/processor relationships. There are many descriptions for the types of relationships that are most frequently used, but a general listing would include:

- Spot market transactions
- Contracts
- Quasi-Vertical Integration, Tapered Vertical Integration
- Cost-Plus Agreements
- Value-added Agriculture/Joint Ventures
- Strategic Alliances

The role of cooperatives also must be investigated as they have long been a mechanism for producers to gain access to input supplies and to shift the power in the market.

Spot Market Transactions

Much of the product currently transacted in agriculture is transacted through spot market transactions. With spot markets, there generally are large numbers of buyers and sellers and the product is traded through auctions, open bids, or from prices based on open market exchange. In spot markets there are multiple buyers and sellers and price usually determines the sale. Undifferentiated bulk commodity agriculture products in the United States are generally traded through spot market transactions. The products usually are considered low-value and are produced on millions of farms spread across the country. Farmers sell to traders, brokers, wholesalers or processors who then distribute them down the supply chain, eventually reaching retailers or for livestock consumption.

Contracts

Contracts in agriculture have been in place for several decades. Hobbs and Young (2000) discuss vertical coordination in agricultural supply chains. They note the trend in the United States away from spot market transactions, toward closer vertical coordination along the supply chain. Contracts become more prevalent as buyers seek to gain access to product, and sellers gain assurance of market opportunity and lower their risks. They note that differentiated products specifically require more coordination. Technology is driving more coordination—as with company-specific crop varieties and large-scale production units. And, that regulation is driving more coordination—as with liability issues, traceability, and product standards. For financial gains, companies are moving toward more coordination, and as consumer preference for certain quality levels and for food safety increases, companies are coordinating with suppliers. Finally, product characteristics often drive coordination as with differentiated products, perishable products, or those with new (enhanced) characteristics.

Mighell and Jones (1963) identify three general classifications of contracts.

1. **Market-specification –** buyer agrees to provide a market for the seller's output. The farmer retains control over the production process and the buyer may assume some risk and the right to make decisions over the timing of marketing. (cattle, malting barley)
2. **Production-management –** buyer specifies and/or monitors production practices, input usage, etc. (livestock, particularly poultry and hogs)
3. **Resource-providing –** buyer provides a market outlet, supervises production practices, supplies key inputs and assumes more risk (buyer may retain ownership of the product, farmer is paid a management fee) (close to vertical integration)

A full discussion of contracts is beyond the scope of this paper. Furthermore, contract law is specific to any one particular country and state. For more information on contract farming internationally, see Farm Management and Production Economics Service, Agricultural Support Systems Division, Food and Agriculture Organization of the United Nations (2004).

Martinez and Davis (2002) suggest that farmers must become more interdependent participants in the food supply chain, perhaps giving rise to more contracting and other forms of organizations in agriculture. They believe that demand for food products in the United States will grow slowly over the next 20 years. Based on that prediction, a food company's growth will depend on lowering production costs, differentiating its products, producing higher quality products at economical prices or expanding international trade. Coordination between agricultural production and processing will be essential to providing consumers with products that meet their demands for quality and variety. Examples of current contracts include:

- Frito-Lay contracts for specific types of corn for its Fritos Corn Chips.
- Smithfield Foods contracts for pork to produce Lean Generation Pork, a lean, branded fresh pork product
- McCain Foods produces one-third of all French fries consumed in the world, potatoes are grown by producers who enter into contracts before the year's crops are planted

The authors note that contracts in the pork industry are increasing (Martinez and Davis, 2002 p. 35):

> "Contract terms typically specify that producers will deliver a certain quantity of hogs to processors at a certain date. Producers may receive a formula-based price typically a hog price at a particular market location (for example, Iowa/Southern Minnesota), with premiums or discounts based on size and quality of the hogs. Processors may also specify that producers use certain types of inputs, such as specific genetic strains. Other types of contracts used in the hog industry give processors more control over the quality of hogs by allowing the processors to provide key production inputs. As in similar arrangements in the poultry industry, pork processors may own the hogs and establish contracts with farmers to feed the animals to market weight."

In addition to the pork industry, more than half of all citrus fruits and processed vegetables in the United States are produced under contract. Contracts give vegetable processors control over planted acreage and planting dates to help ensure that processors receive a regular flow of raw product with desirable traits. Volume requirements of large retailers for items such as branded, fresh packaged salads has created growing interest in contracting as a means of procuring the desired volume, size, variety, quality and consistency of product.

Contracts have been in existence in the poultry industry since the 1950s. The industry has become more vertically integrated and horizontally consolidated with a few companies owning product inputs, processing, wholesaling, and distribution. Some evidence exists that the farmer/producer receives no returns above operating costs after including a modest return on labor and depreciation (Taylor, 2002). He notes that with vertical integration, two conditions must exist for fair treatment of growers. The vertical supply chains must be extremely competitive with each other; as more horizontal integration occurs, there is less competition between supply chains. Second, there must be a balance of economic power between the vertical corporation and the contract grower. In the poultry industry, vertical integration has basically eliminated a spot market for the product, resulting in an imbalance of power in favor of the processor. He suggests that the imbalance in power could be restored through transparency in contracts and eliminating some deceptive practices in the contracts.

There are many examples of how large companies use contracting to gain access to new production locations or markets. Prater, Biehl and Smith (2001) describe the method Pioneer Hybrid used to gain access to Eastern European production sites and markets. Rather than buy land and grow and transport crops of their own, which would be typical in international locations, Pioneer contracted with farmers. The farmers grow and harvest grain, and deliver it to a storage facility. Pioneer provides a contract that guarantees farmers a minimum income regardless of the level of the harvest. Pioneer uses its resources to reduce the farmers' risk of a poor harvest. Pioneer does not need an inbound transport system that could be used on the poor roads in that area. However, the company also does not directly control the farmers and must accept delays in harvest and delivery.

Another example of contract issues can be found in a discussion of contracts in the wine grape industry (see Fraser, 2003). Like other agriculture industries, changes in demand and supply have had an impact on this industry. An overbalance of the grape supply has led winemakers to select which grapes they will use and resulted in strained relationships with growers. The relationship between growers and wineries historically focused on the coordination of grape supply, including crop type and technology (production and processing), perishability and bulkiness which require concentrated production and scheduling. This led to the use of contracts since the early 1990s. Contracts vary significantly in style and content; from informal contracts (verbal/handshake deals) where enforcement is by implicit cultural conventions, reputation, or repeated interaction to formal contracts (written) which may be incomplete in nature as many features are unstated and implicit. Three reasons for contracts in wine grapes are to:

1. Introduce certainty in grape and wine production (allowing for allocation of resources with greater confidence),
2. Allow market participants to share both financial and production risks, and
3. Potentially motivate performance by the use of bonuses and penalties.

The contracts are a trade-off between the extent that the winery provides "insurance" to a grower and the need to provide incentives to the grower to produce high-quality grapes given that the quality is not perfectly observable. The contract is complicated by the ability of the grower to shirk or satisfy the contract in suboptimal ways. Contracts are designed to offer incentives to prevent shirking without incurring excessive risk to the grower. This is implemented through contracts that contain a flat fee (the risk-sharing component) plus performance incentives (bonuses and penalties for quality).

Complicating the contracts are informational problems in the supply chain (i.e., the winery doesn't know what the grower is doing, other than he has a capital investment which signifies his intention to do business). To minimize the effect of such problems, wineries contracts may include:

1. Grower visits to share information on vineyard management, discuss crop development, and coordinate harvest
2. Specifying input use (form of rootstock or choice of irrigation technology)
3. A measure of the quality of grapes supplied (measurement schemes are controversial)
4. Payments that are contingent on the price of wine in the bottle (lot tracing is more readily possible today)

Estimates of grapes grown under contract in both Australia and the United States range from 85 to 90 percent. Contracts have gained in importance when growers seek financial backing from their banks. There is evidence that wineries are seeking security of supply by expanding their own grape production capability,

Some details on the wine contracts provide insight into the basics of other industry contracts (Fraser, 2003):

> **Length** - Contract length is between three and ten years with an average length of 6.9 years in Australia and 3.5 in the U.S.
>
> **Price** - There were numerous methods to set price in the contracts including: minimum price, fixed price for a fixed term with Consumer Price Index (CPI) indexing, market price, market price with fixed minimums and maximums, market price with bonus and penalty schedules and bottle price. Most often used in the United States was a reference price, such as industry-wide information similar to the average district price published by the California Agriculture Statistics Service.
>
> **Harvest** - Contracts detailed harvest timing, method and bins for grape collection in only 25 percent of the contracts. However, wineries dictate when they will take the grapes, so the risks connected with leaving grapes on the vine longer than quality dictates rest with the grower.
>
> **Quality** - Due to an excess supply of grapes, more wineries are including fruit quality requirements in contracts. Most contracts do not include a third-party evaluation of quality, so growers are at the mercy of winery quality assessments.
>
> **Growing practices** - Wineries in general do not dictate viticultural practices but offer advice through regular visits or by dissemination of information through newsletters or grower meetings.
>
> **Dispute resolution** - Some wineries include a dispute resolution method, but it is generally to resolve issues related to quality, not price.
>
> **Contract renewal**- Wineries and growers generally had contract renewal clauses or evergreen clauses which specify the contract continues indefinitely unless one party gives notice of termination (generally two seasons).

Beyond contracts, wineries note the importance of trust and respect in relationships, as everything cannot be specified or enforced in a contract. In times of excess or under supply of grapes, contracts do not necessarily yield the best outcome to either party. There are many issues with how prices are set in the contracts. Indicative prices based on the previous year's price by variety (for example) are only as good as the information in the formula. Also, when there is an overabundance of grapes, wineries may ignore quality incentives as there is an excess of high-quality product. In general, growers will exchange price uncertainty for lower but certain returns.

As is true for many processors, wineries are viewed as having much more power in the relationship, partly because they have access to more information on wine demand and grape supply. This is evidenced by some contracts that allow cancellation based on "market disruption" in the demand for wine. One attempt to equalize the balance of power is for growers to form cooperatives. With a large number of growers and a small number of competitive wineries, it would be reasonable to expect some type of cooperation, but it is not common. The grower industry group is trying to agree to some standards across all contracts and is attempting to write a dispute resolution clause which would be included in all contracts.

Cost-Plus Agreements

Another type of relationship can be defined as a cost-plus agreement, where a processor or downstream supply chain partner agrees to pay the grower based on the actual cost of production. Yakima Chief, Inc., a hops marketing, warehousing and processing company (O'Connell, 2004) is an example of a cost-plus processor. In this case the processing enterprise also is an example of value-added investment, since the growers own the processing company. The company, owned by thirteen grower families, allows growers to maintain title to their hops all the way to the brewery gate. When the brewery pays the Yakima Chief invoice, the proceeds flow back to the grower with the company deducting fees for services performed. The arrangement is different from the standard business model in the hop industry where hops are bought from growers and sold to brewers in the traditional trader/merchant model with margins taken in the transaction. Yakima Chief has formed partnerships with large brewers which focus on cost transparency, tight specifications for better processing, product traceability, food safety and guaranteed supply. Other customers are evaluated for potential partnerships and where the potential exists they are treated much as the partnership companies. Other buyers are viewed as spot buyers and supply is not guaranteed.

As O'Connell describes the partnership arrangements, they are contracts which lay out highly specific terms and conditions covering all aspects of the parties' rights and responsibilities during a multi-year contract. A model is used to identify costs and thereby determine payment. The model presents "all economic aspects of farm production, Yakima Chief processing costs and operational efficiencies necessary to arrive at an auditable product price based upon a transparent formula." The return to the grower is based on the average cost of production in the current crop year, a margin above the cost of production (realizing a return on assets) and three-year averages on yield per acre and product and product viability. Processing cost is reimbursed to Yakima Chief.

The model's success has been attributed to benefits for all three entities—growers, Yakima Chief and brewer customers. The grower receives a known sales volume, has an easily understandable basis of farm return from known price, and his cash flow cycle is reasonably predictable. Yakima Chief has a known processing volume and valuable customers with solid relationships based on mutual benefits. The partner customer gets transparency and traceability back to the grower's field, has his food safety concerns eliminated, receives a known variety (and associated functionality), and known costs and the basis for them. It is O'Connell's view that a similar model could be appropriate to other industries providing the products marketed have a high "Relative Value" in relationship to the starting agricultural raw material. Relative Value is the ratio of "unit price of finished product" to "unit price of raw material." When raw product is strictly traded on a standard contract, commodity-pricing basis without high relative value, the product price will not return a profit after application of costs of processing, information, packaging and customer service. In addition, there must be a committed grower group willing to separate themselves, at least partially, from the “grow and deliver” farm model.

Another example of cost plus relationships is described by Hayward (2003). She describes a program between Asda, a large European retailer and division of Wal-Mart, and carrot farmers in Scotland. Begun in 1999, the “cost plus” scheme guarantees farmers a sustainable income for their crop, which includes a true cost of production. The carrot growers receive a fair price for their produce and have a committed customer for the volume of their product the next year. This initiative is part of a larger program to develop local sources of food in Britain.

Cost-based models for setting prices are being investigated in other industries such as in the transaction between feeder cattle growers and processors (Drovers, 2003). Some researchers suggest that retail prices along with the cost of processing and fabricating should be used to set live cattle prices. The problem with using retail prices is that they are generally not known until several weeks after the sale. Also, the costs of processing, fabrication, transformation, and transportation either are not revealed or are known only after the sale. Processors are not generally willing to divulge their costs, so the process becomes even more difficult as we add exporting and food service into the supply chain.

Fair trade

While not specifically a supply chain, market-based business model, a brief mention should be made of Fairtrade Labelling and the relationships established with producer/growers. Fairtrade was created in the Netherlands in the late 1980s (Fairtrade Foundation, 2004). The label Fairtrade was launched first on coffee sourced from Mexico in 1986 and today the Fairtrade Labelling Organizations International (FLO) sets standards and monitors products sold under the brand name. Producers who register with the organization receive a minimum price that covers the cost of production, they are offered up-front payments and loans, and an extra premium is paid which must be invested in the local community to foster social and economic development. By 2004 there were 360 Fairtrade certified producer groups in 40 producer countries selling to hundreds of Fairtrade registered importers, licensees and retailers in 18 countries.

Fair trade products require the consumer to buy into the concept and be willing to pay an extra premium for the finished product. Examples of success with fair trade can be found at Race to the Top (Pye-Smith, 2004). In 1994, fair trade products retailed for 3 million British pounds and in 2002 they were worth 50 million pounds. Farmers sell through a cooperative which is also part owner in a processing company. The fair trade farmers may make up to twice the normal price for their products, but the amount sold is still very small. Fair trade has been extended from coffee and tea to mangoes, bananas, and chocolate, orange juice and wine.

Quasi-Vertical Integration, Tapered Vertical Integration/Franchise

Three other types of integrations are described by Fearne, Hughes and Duffy (2001). The first is quasi-vertical integration where buyers and sellers form a long-term contractual obligation and both parties invest resources. It is not truly a vertical integration arrangement as the agreement runs for a fixed time period and the firms remain independent. An example might be a joint venture where participants share the costs, risks, profits and losses, or a franchise or licensing agreement. A second type of integration is described as "tapered vertical integration" where a firm receives part of its supply through backward integration. For example, a beef processor may own some cattle on its own farms and buy the remainder from auctions or direct from farmers. The third type of integration is full vertical integration where a firm owns two or more segments of the supply chain.

Some authors suggest that franchising might be an appropriate model in some agriculture supply chains (Hobbs and Young, 2001). With franchises, a company (the franchisor) contracts with the franchisee to provide a branded product or service. The franchisee generally pays an up-front fee to cover training and facility development and a royalty on revenue. The advantage to the grower is that the product is branded and they benefit from good decision-making skills and risk sharing.

The Value-added Agriculture Model/Joint Ventures

A recent trend in agriculture is for groups of growers to make investment in further processing their product (often termed value-added agriculture). Value added means that firms or groups of independent producers form a partnership or acquire a firm to complete another process stage, either upstream or downstream, in the supply chain. Some kind of value must result from the new business and result in increased profits for the investors.

Evidence from previous research at Purdue University (Fulton, 2000) suggests that in some cases the investment can be profitable for the producers. The farmer diversifies his investments beyond the farm, possibly into a more profitable business segment, and may benefit from government subsidies or incentives (as with ethanol production). However, in industries where rivalry among competitors is intense (as in the corn sweetener business) there is solid evidence that the existing competitors would react strongly to a new entrant and decrease the likelihood of profitability. Furthermore, it is difficult to get producers to commit to support an alliance over the long term and not to defect when prices elsewhere are higher. Fulton describes the necessary conditions for success as trust, commitment for the long run, communication, financial stability, positive benefits from working together, a small number of similar players, penalty for defectors, and a mechanism to share profits, losses and risk.

Nitschke and O'Keefe (1997) discuss the issues surrounding this business model in their evaluation of an Australian grain coop and its move to become a grain marketer, not just a grain trader. They note that value creation is not just the domain of individual firms, but rather is accomplished by a system of businesses including retailers, exporters, packers, growers, input providers, manufacturers, etc.

> For example, in horticulture, an Australian pear grower does not simply compete in Asian markets with a Chilean or South African pear grower. But the system of Australian growers-packers-exporters competes against the business systems of Chile or South Africa. It therefore follows that the competitiveness of the system is dependent on both the competitiveness of individual firms and the nature of the linkages between firms along the value chain. Further, the co-ordination mechanisms that are suitable for commodities – such as auction systems – are not appropriate for differentiated products and segmented marketing strategies. (Nitschke and O'Keefe, 1997 p.4)

They note that closer vertical coordination requires the farmer to relinquish control. However, farmers (in this case Australian farmers) generally place a high value on their independence and are extremely reluctant to cede any control or independence, especially to another party with whom they traditionally have had an adversarial relationship. Growers that used auction systems maximized their independence but their risks also were at a maximum. And, with independence and auction systems they did not receive specific customer feedback and they tended to be isolated from the rest of the supply chain.

They also noted that there are implications based on the size imbalance between individual growers and processors. When there are unbalanced relationships, such as the size imbalance between growers and processors, there are likely to be lower levels of cooperation and trust, higher levels of conflict and more instability. This has led growers to evaluate opportunities for further ownership down the supply chain into processing or even owning retail outlets for their product.

Strategic Alliances

Another type of relationship found in agri-industries and identified by Hobbs and Young (2000) is the strategic alliance, where both parties share the risks and benefits and both make decisions. These relationships often are flexible and trust-based and both parties work towards a mutual goal. Both groups use their complementary assets to gain long-term competitive advantage. The relationships are often very broad and difficult to define by contract and generally need to be built over time. An example would be hogs that are sold to a specific processor by a group of producers who agree to meet certain quality characteristics. The processor also may have an alliance with a retailer who provides a branded product.

Hobbs and Young (2000) go on to identify implications of these new relationships for producers, producer cooperatives or commodity groups, and the government:

> **Producers –** can add more value to their crops, must have new management expertise to evaluate production, marketing and relationship risks, need new skills in contract evaluation and negotiation, must understand the quality traits required by the buyer, and market price information is less valuable. Risk increases if the producer makes specific asset investments.
>
> **Cooperatives or commodity groups –** increased role as intermediary to reduce negotiation costs between producers and processors, guarantee source of supply (to support a new processing plant), and may play a role in monitoring quality. The traditional role of lobbying for price floors may change to lobbying for things such as increased access to international markets.
>
> **Government –** as identity-preserved products increase, commodity-oriented policies will become less relevant which reduces the need for average market price reporting by public agencies. This will be determined largely by how much of the overall volume is sold through identity-preserved supply chains. Today, these quantities are low, but growing.
>
> **Commodity groups –** establish and operate quality assurance plans, monitor crop quality (especially for trait-specific products whose characteristics are not visible).

Adams and Goldsmith (1999) describe relationships which they call strategic fuzzy alliances. They describe these as trust-based relationships with the following characteristics: the boundaries between the firms are flexible and much less clear; there is shared control between the firms; knowledge flows easily between the firms; success is based on cooperation and using each other's ideas to advance both firms; innovation and learning are encouraged to keep pace in the industry; in case of failure, exits costs are low and relations can be broken easily; partners are stakeholders but not necessarily shareholders in the operation; and the relationship is based on trust rather than being contract based. In fact they argue that without trust, fuzzy alliances cannot exist. For trust to exist they have found that knowledge of the other party's business and the industry is required; predictability of the other firm or individuals must be present; the individuals or firm must have free will to trust the other; and finally, risk must exist because when outcomes are assured, there is no need for trust. Trust-based relationships do not require contracts or incur the costs of contracting; however, they incur the costs of acquiring knowledge of the other firm and building relationships.

The Role of Cooperatives

Agriculture cooperatives have long been a mechanism for producers to gain access to supplies and power in the market. Plunkett and Kingwell (2001) provide a taxonomy of cooperatives in Australia that illustrates their form, role, capitalization and level of producer commitment (see Table 3). The authors note that processing of farm products typically is capital-intensive, increasingly knowledge-based, and requires investment in technology, facilities and management. The structure of new generation cooperatives facilitates investment in such activity. By including delivery rights in shares, start-up funding is increased and borrowing requirements reduced. The quantity and quality of product is assured through delivery contracts. Other benefits to producers include: reassurance that other members are not able to behave opportunistically with regards to supply and quality of that supply, information about what is valued in the market, and reduction of risk. However, like any investment they are not without risk. Marketing cooperatives are a type of vertical integration, where the farmer owns assets further down the food processing or distribution system (Hendrikse and Bijman, 2002). Cooperatives are based on democratic decision making and raising equity capital among members.

Table 3: Taxonomy of Co-operatives

	Cooperative associations	Service cooperatives	Supply cooperatives	Simple marketing cooperative	Processing and marketing cooperative (Traditional)	Processing and marketing cooperative (New generation)
What they do	Member education; Product promotion.	Provide business management services, etc.	Provide inputs and services for agricultural businesses.	Negotiate prices; co-ordinate distribution.	Process and market members' raw products.	
Capital requirements	Usually very minor.	Can be minor, depending in the service.	Start-up costs reflect building costs and equipment.	Moderate start-up costs.	Typically involve significant start-up costs and require regular reinvestment to upgrade equipment and expand marketing.	
How they are capitalized	Usually a nominal annual fee.	The co-op may borrow from members, from lenders, or sell stock or capital certificates to cover start-up costs. Thereafter, surplus from service fees and prices for goods may be allocated to member accounts but retained for a limited time to meet capital requirements.		The co-op may borrow from members, from lenders, or sell stock or capital certificates to cover start-up costs. Thereafter, capital retained is via charges per unit of members' product that is processed and/or marketed through the co-op.		Limited number of preferred shares sold to qualifying farmers at a price that reflects overall capital needs.
How equity is returned	Usually is not returned.	Typically revolved back to members over time.				Trade shares to other or new members. Share value reflects the co-op's performance.
Level of product commitment	NA	NA		NA	Contracts may (or may not) bind a member to commit all or a set portion of his total production, but fixed quantities are usually not contracted.	Each purchased share commits a member to a specific quantity each year.

Source: Plunkett, B. and R. Kingwell, "New Generations Co-operatives for Agricultural Marketing and Processing in Australia: Principles, Practicalities and a Case Study," Agribusiness Review Vol. 9 (2001)

New generation coops (NGCs) are like coops in that each member has one vote and receives a distribution of profits based on patronage. With a NGC, a producer can own a piece of the processing, wholesale, distribution or retail sectors, and potentially earn a return on investment at any stage of the process. In addition, NGCs can issue shares that carry the right and obligation to deliver a specific amount of product to the coop. Members delivering their product into the system can expect an annual return on their investment in the form of patronage premiums. NGC shares are tradable and redeemable allowing members to get their equity out of the venture when they retire or quit farming. NGCs can have restricted membership and new members may have to purchase or lease delivery shares from someone else to become involved.

Parkland Industrial Hemp Growers Cooperative in Dauphin, Manitoba, Canada is a producing a biobased product using a NGC framework (BioProducts Canada, 2004). One hundred seventeen farmers organized in 1998 to produce hemp seed for processing into nutraceuticals, hand lotions, livestock protein supplements, birdseed and other items. After losing a major customer, the coop began processing hemp fiber for bedding for horses, strong paper and super-soft liners for winter boots. The NGC structure follows one established in the United States in North Dakota and Minnesota in the 1990s (Agriculture, Food and Rural Development, 2004). Some of the other NGCs in the United States include: Dakota Growers Pasta, the North American Bison Co-op and U.S. Premium Beef. Further information on NGCs can be found in an article on U.S. Premium Beef (Katz and Boland, 2000).

Agricultural Business Structures

Many companies, including agricultural companies, have adopted an integrated production and processing supply chain framework for organizing to meet end consumer demand. Supply chain management emphasizes the importance of communicating end customer product needs and specifications back through the supply chain to processors and producers. The goal is for the members of the chain to work together to remove barriers and bottlenecks in the chain and focus on reducing costs and improving quality at each stage. There is a consensus that development of biobased industries requires closer relationships between producers, processors and consumers along the supply chain. The issue for researchers is to determine what the nature of these supply chain relationships should be and how the farmer can maintain profitable participation in these new supply chains.

Ricks, et al. (1999) describe a number of common supply chain management needs from the perspective of an agricultural commodity industry, specifically the produce industry. These include (p. 47):

1. Development of a marketing or customer needs perspective and guidance of strategic directions versus a production perspective.
2. Analysis of the industry's primary customer needs, the value chain, and hence opportunity for market expansion by the industry through the more effective servicing of changing customer needs.
3. Acquisition of continually updated information on the preferences, needs, and requirements of the industry's customers.
4. Production and supply of and adequate quality of products to the industry's customers, development and adaptation of new varieties, new products, and new uses of the industry's products for changing customer needs.
5. Supply of consistent, adequate, but not surplus volumes when needed by customers.
6. Provision of consumer access through retail grocery shelves and through the menu offerings of food service retailers.
7. Means by which to overcome common obstacles for effective supply chain management from the commodity industry's perspective including limited grocery shelf space, grocery firms' category management, and slotting fees.

8. Development and expansion of export markets by meeting the special requirements for these markets in various export-receiving countries.

They conclude that supply chain management strategies have been less well-developed at the farm level than for the other downstream firms. The farmer is typically focused on production of traditional crops at the lowest possible cost.

To begin to evaluate appropriate supply chain strategies for farmers, Tables 4-9 have been created to summarize the benefits and disadvantages for a number of different types of relationships. The tables identify the benefits and disadvantages for each supply chain member, including the community where the farmer/business resides. The relationships between supply chain partners further downstream from the processor may take many forms and are not dependent on the relationship between the farmer and the processor.

Table 4: Spot Market Transactions for Growers

Business Model		Benefits	Disadvantages
Spot market transactions			
	Grower	* Known price * Available outlets * Established supply chain	* Price may be less than cost * No negotiation opportunity * Does not consider product characteristics * Lack of concern for sustainability by buyers
	Processor	* Competitive bidding * Low or best price * Consistent supply * Potential high profits	* No guarantee of supply * No differentiation of product * No quality assurance * Lack of product traceability
	Further Processor	* Low or best price * Potential high profits	* No differentiation of product * Lack of product traceability
	Retailer	* Low or best price	* No differentiation of product * Lack of product traceability
	Consumer	* Low prices	* No differentiation of product * Lack of product traceability
	Community	* Profitable businesses	* Unprofitable growers * Disregard for environment * Unsustainable long term growers

Table 5: Contract Transactions for Growers

Business Model		Benefits	Disadvantages
Contracts			
	Grower	* Known price * Assurance of market * Lower risk * May differentiate product * Improves traceability * Quality specified * May share financial risk * May receive incentives for some measure of output * Minimal transaction cost	* May lose control of production process * May lose control of inputs * May become process managers with little decision making * May not provide a return above operating costs * Quality monitoring may be skewed by the buyer * Risks of harvesting based on timing of processor demand
	Processor	* Access to product * Known price * Regular flow of product * Desirable product traits * Quality specified product * Consistency of product * Access to markets * Payments may be based on product quality or tied to end product price * Favorable cancellation policies * Minimal transaction costs	* Product may be poorer quality * Volume of product provided may not match demand * May increase financial risk * May increase cost of monitoring production * May be a disincentive for input improvement * May pay higher price
	Further Processor	* Improved traceability * Consistent product * Stable price of product	* Price may be higher * Volume limits may force purchase from multiple suppliers
	Retailer	* Stable product price * Promote known sources of products (locally grown)	* Price may be higher
	Consumer	* Improved traceability * Stable price	* Price may be higher * Reduced choice of product
	Community	* Can identify sustainable grower/processors * Profitable businesses	* May be unprofitable for growers * May be unsustainable long term for growers

Table 6: Cost-Plus Contract Transactions for Growers

Business Model		Benefits	Disadvantages
Cost plus contracts			
	Grower	* Price covers cost of production * Lower risk * May differentiate product * Improves traceability * Quality specified * Reduced financial risk * Multi-year possible * Payment determined by cost of production formula * Reasonable cash flow cycle * Access to a committed customer	* Cost of identifying costs * Cost must include a return to operation * Increased transaction cost * Risk of cost being provided to competitors * Implied trust in the relationship * No guarantee of return when yields are poor * Information system required to capture and exchange cost information * Must have a group of committed growers to make feasible
	Processor	* Known processing volume * Price downstream can be negotiated based on input costs * May differentiate product * Improves traceability * Quality specified	* Variability in price over time * May be higher price * Increased transaction cost * Cost of information system * Customer may go elsewhere when market price is lower
	Further Processor	* Traceable product * Specified quality * Product differentiation possible	* Price may be higher * Price may vary with cost *
	Retailer	* Traceable product * Can promote a product feature	* Price may be higher * Price may be more variable
	Consumer	* Differentiated product * Improved traceability	* Price may be higher
	Community	* Can identify sustainable growers/processors * Profitable businesses	* May be unsustainable long term for growers

Table 7: Partial Vertical Integration Transactions for Growers

Business Model		Benefits	Disadvantages
Tapered vertical integration/ Quasi-Vertical integration/ Franchise			
	Grower	* Long-term agreement * May maintain ownership independence * Share costs and risks * Provides basis for financing	* May be virtually an employee of the processor * May share in losses * May have little decision-making authority
	Processor	* Can specify inputs and other traits * Control of grower process * Quality standardized * Guaranteed supply * Differentiate product * Improved traceability * Price predictable * Lower transaction costs	* Higher investment * Tighter coordination required with growers * Legal limitations
	Further Processor	* Differentiated product * Improved traceability	* Higher prices * Lack of access to some product
	Retailer	* Differentiated product * Improved traceability * Can promote a product feature	* Higher prices * Lack of access to some product
	Consumer	* Differentiated product * Improved traceability	* Price may be higher
	Community	* Profitable businesses	* May reduce the number of growers

Table 8: Partnerships/Joint Venture Transactions for Growers

Business Model		Benefits	Disadvantages
Value-added agriculture/ Partnerships/ joint ventures			
	Grower	* Increased profits * May improve government subsidies * Share losses and risks * May differentiate product * May improve traceability * Better feedback from downstream customers	* Requires long-term commitment * Requires a committed group of partner/growers * Defectors can sabotage the venture * May give up some control * Increased risk of secondary venture * Lack of knowledge in secondary business * Costs of financing
	Processor	* Guaranteed source of supply * Traceability * Product differentiation possible * Source of financing * Share risks and losses	* Grower/owners may have little processing knowledge * Growers may defect * Must compete with other supply chains
	Further Processor	* Traceability * Product differentiation possible	* Possible higher prices
	Retailer	* Traceability * Product differentiation possible * Can promote product feature	* Possible higher prices
	Consumer	* Traceability * Product differentiation possible	* Possible higher prices
	Community	* Jobs and tax increases from new businesses * Sustainability of growers * Potential for sustainable practices	* May require government support for growers and businesses to be profitable and sustainable

Table 9: Strategic Alliance Transactions for Growers

Business Model		Benefits	Disadvantages
Strategic alliance			
	Grower	* Secure and stable market * Agreed-to price or price structure plan * Share risk * May differentiate product * Improves traceability * Quality specified * Reduced financial risk * Multi-year possible * Access to a committed customer	* Relationship is based on trust * No penalty for processor defecting * Requires sharing detailed information including costs * Increased relationship costs * No guarantee of return * Information system required to capture and exchange information * Must have a group of committed growers to make feasible * Give up some independence
	Processor	* Reliable source of product * Agreed-to price or price structure plan * Share risk * May differentiate product * Improves traceability * Quality specified * Reduced financial risk * Multi-year possible	* Relationship is based on trust * Growers can defect and product supply disintegrate * Requires sharing detailed information * Increased relationship costs * Information system required to capture and exchange information * Must have a group of committed growers to make feasible
	Further Processor	* May differentiate product * Improves traceability * Quality specified	* Possible higher prices
	Retailer	* May differentiate product * Improves traceability * Quality specified * Can promote product feature	* Possible higher prices
	Consumer	* Traceability * Product differentiation possible	* Possible higher prices
	Community	* Can identify sustainable growers/processors * Potential for sustainable practices	* Supply chains must be competitive for all partners to be sustained

As producers look to develop relationships with major manufacturers and retailers, individual farmers may want to consider aligning themselves further down the supply chain and think about certain necessary elements (Thompson, 2001). The key requirement is for an integrated system which links production with point of sale allowing information to flow up and down the supply chain. The product must be of the highest quality and meet all the regulatory and consumer requirements. The producers must be able to provide a consistent supply of product. They should consider linking with processors who have the initiative and capacity to develop new products. At the same time, they must work with buyers to provide price stability. Farmers must acquire a marketing perspective of the supply chain rather than a production view and have a preference for long-term commercial relationships

The agricultural food industry has been slow to build trust-based relationships between supply chain partners. O'Keeffe (1998) identifies four key characteristics which hinder trust-building in agriculture supply chains:

- In commodity markets the sum of value created is fixed and the major issue is how it is divided among channel participants. This is a win-lose game and leads to adversarial relationships;
- Auction systems and regulated markets isolate farmers from the rest of the food system and farmers do not gain any insight into their customers, and why they act the way they do. Likewise processors have not needed to, or had the opportunity to, develop relationships with growers;
- Supply chain management does not remove the volatile nature of prices and supply – both quantity and quality - characteristic of agriculture. Price volatility puts pressure on the relationship;
- Interdependence is difficult to achieve owing to size imbalance between processors and farmers.

These issues must be considered as farmers move to change the nature of the relationships in their particular supply chains.

Conclusions

The purpose of this paper is to investigate supply chain business relationships that would be most appropriate for biobased businesses. A framework is required that identifies the business structures available to farmers producing products to serve the new bioindustries *which translate into wealth creation for farmers*.   Clearly, the ***manner*** in which biobased businesses are developed will have tremendous implications for the future wealth of Iowa's farmers and communities and for the economic condition of the state. While there may be great opportunities for large-scale farms that use best practice management standards to succeed in the new bioeconomy, it is more difficult to envision the role of the mid-sized farmer. How should these farmers look to improve their profitability as they begin providing products to biobased processing companies?

An initial literature review provided a background on supply chain practices and identified best practices in supply chain management. A discussion of existing agricultural business supply chain practices was included. Finally, a complete discussion of possible business structures was developed along with an analysis of benefits and disadvantages for all links in the supply chain. While none of the models provides the perfect solution for farmers, the benefits of long-term strategic alliances that are based on trust between partners appear to have the most potential for new biobased businesses.

There are several limitations associated with these findings. The purpose of this research was to identify possible business supply chain relationships that would provide an equitable return to farmer/producers. The scope of the research was too broad and was difficult to cover fully in a reasonable literature search. In formal peer-reviewed agriculture journals alone, a 2001 study found a total of 123 journal articles relating to chain management in the agri-food industry

Cunningham (2001). Those were articles published prior to August 2000. The number of articles since that date is likely to be significantly higher. These numbers indicate the difficulty of paring down this amount of literature in a reasonable review. Articles could be segregated by commodity type and country or continent but that does not suggest how they might aid in a review of business relationships. In addition, many other government reports and private company analyses also are readily circulated and available via the Internet. Supply chain literature in general is extensive, including numerous journals, books and web site publications which could apply to agriculture. The result was an exhaustive group of materials to evaluate and no reasonable method to segregate it for this project.

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